



agriculture, nature
and food quality



Environmental Impact Assessment of the pangasius sector in the Mekong Delta

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With contributions from: P.T. Anh, V.V. Dung, M. Fransen, H.T.T. Hien,
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WAGENINGEN UNIVERSITY
University for Life Sciences

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Executive Summary

In the past seven years the export of white pangasius fillets grew fast. The culture method shifted to intensive production of striped catfish (Ca Tra) in deep ponds because this is more efficient than the pen and cage culture of Ca Basa. Today, striped catfish comprises more than 90 % of the culture. The increased production was achieved by producers investing in large ponds. The market chain is gearing towards vertical integration.

Most farms keep fish at relatively high densities of 15 to 25 fish/m³ in ponds having a depth of up to 4m, and are advised to exchange daily 20 to 40% of the water. The sustainability of the sector is threatened due to the increased environmental pressure, and hampered by the growing cost of inputs and reduced farm-gate prices of the fish.

The Environmental Impact Assessment (EIA) intends to identify measures for preventing or mitigating the environmental impacts of catfish culture in the Mekong Delta. The EIA was a seven-step process during which we interacted twice with part of the main stakeholders. To build trust among the stakeholders from the sector, we conducted the scoping and goal setting with them. We also discussed preliminary results with the policy makers and the stakeholders.

Methodology

The EIA followed the Life Cycle Assessment (LCA) methodology that consisted of four related phases. The LCA used a screening character with worst case scenarios for less crucial processes, and focused on processes that could be affected by decisions based on the LCA. The initial LCA was iterative which allowed us to adjust choices and to insert complementary information.

The first stakeholders meeting specified choices on system boundaries and on the functional unit. During a subsequent meeting, the study team specified choices on data collection and data requirements, on allocation, impact categories, tools for interpretation, as well as, the study's assumptions and limitations. The stakeholders proposed to set the system boundary at the farm-gate because good policies and technologies were available for the processors; the production of inputs was included. The functional unit was 1000 kg of fish (1 metric ton). The LCA focused on ponds; particularly on striped catfish. Next to the environmental impacts, this EIA also addressed specific issues that are a concern to stakeholders such as water quality and other effects of medicine use. The inventory analyzed the product system and collected relevant input and output data. For each process, the sample size was based on six aspects of data quality. The inventory data for the production of energy, feed and other inputs, were for the larger part taken from available databases such as EcoInvent 2.0, that were available in the LCA software SimaPro 7.1. The inventory data for the rice production were adjusted to the local practices.

According to refereed methods, the contributions to a number of impact categories were quantified: Global Warming (GW); Acidification (AC), Eutrophication (EU), Energy Use (EC); Human toxicity (HT); Freshwater ecotoxicity (FWET); and marine ecotoxicity (MAET). Resource use was included as water use and as loss of biodiversity (BD). Loss of BD was separately considered as aquatic and terrestrial biodiversity. Terrestrial BD was evaluated as Mean Species Abundance (MSA) for the terrestrial environment. Characterization factors for the effect on aquatic biodiversity were not available and this impact was described and expressed as fish feed equivalency (FFE). The stakeholders requested to consider other pollutants, and to consider the rivers' total carrying capacity and variation of its flow.

Inventory analysis

Inputs and outputs of 28 grow-out farms and of 4 hatcheries/nurseries were collected. Data on water and sludge quality came from other surveys. The 28 farms reached an average yield of close to 300 t/ha per crop with a mean FCR of 1.86. For pond preparation, farmers used mainly products without harmful environmental impact downstream, such as lime (5 kg/t fish).

Producers also used medicines containing antibiotics (0.15 kg/t fish). Calculated average pond volume was close to 130,000 m³; daily refreshment rate was 7%. About 9,750 m³ water per ton fish was refreshed. This used close to 2 % of the water flowing through the Mekong river.

The densities of fish in the hatcheries and nurseries were low; and producers used less than 0.5% of the inputs used in grow-out farms. Therefore this process was not included in the LCA.

From the over 30 companies producing feed, five provided detailed information on request. Feed factories specified water and energy use and some parameters of the catfish feed. Ingredients for catfish feed came from 14 countries from all over the globe. Especially high quality feed ingredients were imported. Allocation of impact from sub-systems was based on physical relation; e.g. we allocated for rice-bran 10% of the impact attributed to the production of rice.

Both factories and farms used electricity, but transport to the processing company was not included. Average distances for transport by sea and by road of ingredients to the feed processing plant were implemented. Transport distance of inputs to the farm, estimated at 100 km, was included in the farming process. We made an educated assumption on the electricity production with regard to the energy sources and the distribution network.

Land-use changes since 2000 on river banks, outside or inside the flood protected area, were identified and classified for MSA type and sensitivity to erosion. Impact on aquatic biodiversity had two aspects: (1) fishmeal and fish oil came from various Asian countries, and (2) these originated both from inland and marine catches. The average FFE of 7 feeds was 1.34 and varied between 0.7 and 2.6.

We distinguished two types of waste water: for daily refreshment and to discharge sludge. Content of N, P, and COD in discharge water was corrected for quality of inlet refreshment water. Next to waste discharge through daily water refreshment, three scenarios of sludge and sediment discharge were calculated: (1) the worst case discharges of sediment and sludge, (2) the most probable case pumps sludge monthly, and (3) the best scenario uses a sedimentation pond and only discharges effluent. The N discharges in the best, most probable, and worst cases were: 0.14, 2.2, 7.9 kg/t fish; respectively. While for the P discharges in the best, most probable, and worst case were: 0.04, 0.2, 3.6 kg/t fish; respectively.

Impact assessment.

Feed contributed most to the environmental impact (EI) of the pangasius farms; the contribution varied for the impact categories. The origin of the ingredients was important for the impact on marine ecotoxicity and on biodiversity. Among feed ingredients, rice bran dominated for GW and AC due to the quantity; while wheat bran dominated for EU. The transport and the energy processes dominated toxicity categories, next to fishmeal production.

Contribution to the total suspended solids of sludge from the ponds was limited because sedimentation and mineralization occurred at the bottom if the sludge was left in the ponds during the production cycle. N discharge was probably close to 2% of total N in river. Water withdrawal from the river was estimated at 2%, but most was restored as green water. Real water use was limited to 3650 m³/t fish which was lower than that used for most animal proteins.

Close to 6000 ha of pangasius culture area is constructed inside the river banks, which occupies less than 0.5% of the flooding area. Less than 0.5 % of the culture area increases erosion risk along 3.5 km of flood protection dikes in two communes. The reduction of terrestrial biodiversity within the Mekong Delta is estimated at 0.24 %. For most commercial feeds, the use of fish for feed is inefficient. A small fraction of the fish caught in Vietnam might be attractive for humans after their grow-out.

The medicine use is relatively high but its impact light. If the waiting period of one month before processing is respected, most used medicines are harmless. Farmers' information on medicines seems subjective and uniform advice on good management practices (GMP) is urgent.

Interpretation

The impact on most categories is not limited to Vietnam. Hotspots are the production and transport of feed and the ponds' discharges. Feed with a lower FCR would make a difference if farmers use them. The origin of the ingredients is important for the impact on marine ecotoxicity and biodiversity.

To mitigate impact, feed companies can also influence other aspects of feed quality, such as water stability of feed and faeces. Deposition or recycling most of the sludge on-land would improve sustainability of the sector and the farm enterprises, and may contribute to mitigation of effects from climate change. Discharge from ponds was equal to or smaller than that of the other sectors, but less toxic than the effluents from industry. River water quality in flooding season was not significantly better, and had a tendency to decrease especially during dry season. Though fishpond's discharge was less toxic than effluents from other sectors, high seasonal discharge might have contributed to the perturbation of aquatic ecosystems and affected other economic sectors.

In the Mekong Delta, the impact on land use and terrestrial biodiversity is limited because most areas used were already cultivated. Land use changes and biodiversity effects from feed production were not included in the study. However, using soya bean (meal) probably has impact on deforestation in Brazil. Using fish for feed remains inefficient (FFE between 0.7 and 2.6). The impact on aquatic biodiversity through the use of fish for feed and the discharges is hard to distinguish from other sectors. Though the impact on aquatic biodiversity is not only due to the sector, these changes might negatively affect other economic sectors.

Conclusions

The results of this study show the stakeholders "hotspots" which they can focus on to mitigate the cradle-to-farm-gate environmental impact of the sector. The analysis enabled the researchers to distinguish between the impact of the pangasius culture on the Mekong river and the environmental impact outside the Mekong delta. The feed production, which largely takes place outside Vietnam, dominated the environmental impact from the striped catfish production system. Nevertheless, a considerable part of processes taking place in Vietnam contributed to eutrophication and freshwater ecotoxicity. The contribution of farming to eutrophication largely depends on whether or not the sludge is discharged in the river. About 2% of the Mekong river water passes through the pangasius ponds. The effect on water quality is limited because sedimentation, mineralisation, and infiltration occur in ponds. The contribution of the production ponds to water pollution depends on the way farmers manage their sludge. In the worst case, the sector contributes 2.4% to the N and 3.7% to the P content of the river; while on-land sediment recovery and recycling may reduce these with over 90% to less than 0.05%. To reduce the environmental impacts, this study recommends putting in place policies in the Mekong Delta that would encourage farmers to produce feed ingredients locally, to process feeds with lower FCR and FFE, and to properly manage the sludge.

Recommendations for policy makers:

- Stimulate production of feed ingredients in the Mekong delta.
- Make compulsory the inclusion of FFE and FCR in the declarations of feed quality, and establish control mechanisms.
- Stimulate Good Management Practices for chemical and medicine use, and improve control on trade of illegal products.
- Stimulate farmers to remove sludge and sediments after harvest only, and to respect other technical conditions of the regulation.

Recommendations for feed producers:

- Produce feed with lower FCRs and FFEs, that also results in sticky faeces that do not easily fall a part in the pond' water.
- Mention the estimated FCR and the FFE on the quality labels.
- Use feed ingredients produced in the Mekong delta.

Recommendations for pangasius farmers:

- Use feed with a low FCR and a low FFE.
- Respect good management practices with regard to chemical and medicine use, and with regard to water, sludge and sediment management.
- Recycle the sludge and sediment as a fertiliser, either by letting the sludge settle in the pond before depositing it on-land, or by using a sedimentation pond if regular removal of sludge is needed, before depositing it on-land.

Recommendations for research:

- Identify an efficient system of waste (water, sludge, and sediment) recycling that produces fertilisers from N and P, and energy from the organic waste.
- Identify the optimal feed composition both for a low FCR, and for faeces with high water stability to optimize nutrient recovery from sludge and sediment.
- Identify the optimal ratio between production and sedimentation in the pond.
- Study the fertiliser value of the sludge and sediment from pangasius ponds, i.e. the complements needed for a recommended dosage for various crops.
- Identify the interesting fish species of the genera *Decapterm* and *Cynoglossus* that might grow-out to a size attractive for human consumption, and tools to prevent their catch for sauce and feed.
- Collect evidence for farmers that using feed with low FCR improves their cost/benefit ratios.
- Collect evidence for both processors and farmers that respecting contracts is at long-term beneficial for them, especially if producers act collectively.
- Quantify the methane emission from the deep pangasius ponds.
- Extend the LCA to include processing, deep-freezing and transport, and overall terrestrial biodiversity; and make a comparison to production elsewhere.
- Make a more thorough LCA of feed production to improve data quality of inventory data, and of alternative feed productions and compositions.
- Make an LCA of the system consequences of proposed environmental improvements in the pangasius sector.

1 Introduction

1.1 Aim and process

The EIA intends to identify measures for preventing or mitigating the environmental impacts of catfish culture in the Mekong Delta.

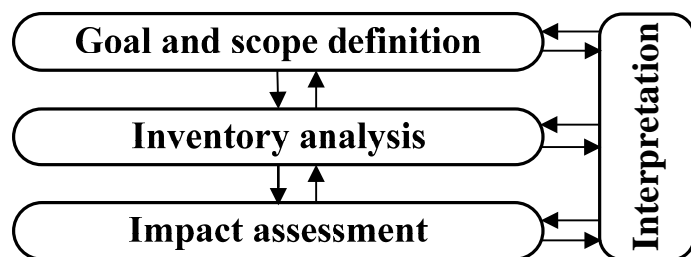
The EIA will follow the ISO 14044 framework for Life Cycle Assessment (LCA) that consists of four related phases.

In 2008, an Environmental Impact Assessment (EIA) of the pangasius sector in the Mekong Delta was done upon demand of the Vietnamese Ministry of Agriculture and Rural Development (MARD). The Dutch ministry of Agriculture, Nature and Food-quality (LNV) agreed to fund this EIA in the framework of the World Summit of Sustainable Development (WSSD). The EIA intends to objectively inform the stakeholders of the pangasius sector on its environmental impact and therewith give directions on the policy measures that may prevent or mitigate this impact.

Various EIA methods are practised, covering different aspects and being complementary to each other (FAO, 2007). The main method used here is Life Cycle Assessment (LCA). LCA systematically evaluates the environmental aspects of a product or service system from resource extraction, through material production, product manufacture, product consumption up to and including processing of the disposed product. An LCA can be used to identify hot-spots in, and to evaluate trade-offs between life cycle stages and between environmental impacts from changes in a product system. This information is instrumental for priority-setting, and for intervention-guidance in environmental policies. The main purpose of an LCA is the environmental optimization of product systems through a “cradle to grave” analyses. It is a standardised approach consisting of four phases (ISO 14044, 2006): goal and scope definition, inventory analysis, impact assessment, and interpretation (Figure 1.1).

Figure 1.1

The four related phases of an LCA.



The initial LCA was iterative which allowed us to adjust choices and to insert additional research to provide complementary information.

It is generally recognized that the goal and scope definition is important in LCA because its results depend on the decisions taken in this phase. Another important notion of the ISO 14044 is the iterative character of LCA. All phases may have to be passed through more than once due to new demands posed by a later phase. A screening LCA may represent one of such iterations as it is a useful way to check and adjust the decisions taken and the choices made in the goal and scoping phase. An initial screening makes it easier to plan the rest of an LCA, including additional research activities necessary for a specific project. The terms of reference for the requested EIA specify that some environmental impacts, such as water quality parameters should be reported on in particular. Some of these are not reported in the preferred level of detail in the LCA; therefore this LCA will be completed with additional information concerning the environment.

1.2 The catfish sector in the Mekong Delta

In the past seven years the export of white pangasius fillets grew fast. The culture method shifted to intensive production of striped catfish (Ca Tra) in deep ponds, because this is more efficient than the pen and cage culture of Ca Basa. Today, striped catfish comprises more than 90% of the culture.

In the Mekong delta production of pangasius for export started with the cage culture of *Pangasius bocourti* ('Ca Basa' in Vietnamese) while production of *Pangasianodon hypophthalmus* or striped catfish ('Ca Tra') for private consumption and local market was done in small ponds. Between 2002 and 2007, the pangasius catfish production in the Mekong Delta increased eightfold from 0.15 to nearly 1.2 million tonnes/year, mainly for export (Figure 1.2). Commercial pangasius farming shifted from growing fish in cages and small extensive pond systems to intensive pond feeding for two reasons. (1) The colour of the flesh of pangasius raised in the extensive ponds is yellowish, while that for export markets require a white fillet. To produce the latter a regular water exchange and specific feeding are needed. (2) The financial margins of raising striped catfish in intensive ponds are better as the fingerling production is relatively easy and less feed is spoiled compared with that of the cage culture system for Ca Basa. These factors caused a parallel shift in species and culture systems (Figure 1.2). Both species are similarly processed, packed, and sold as one product 'Pangasius', indistinguishable by consumers.

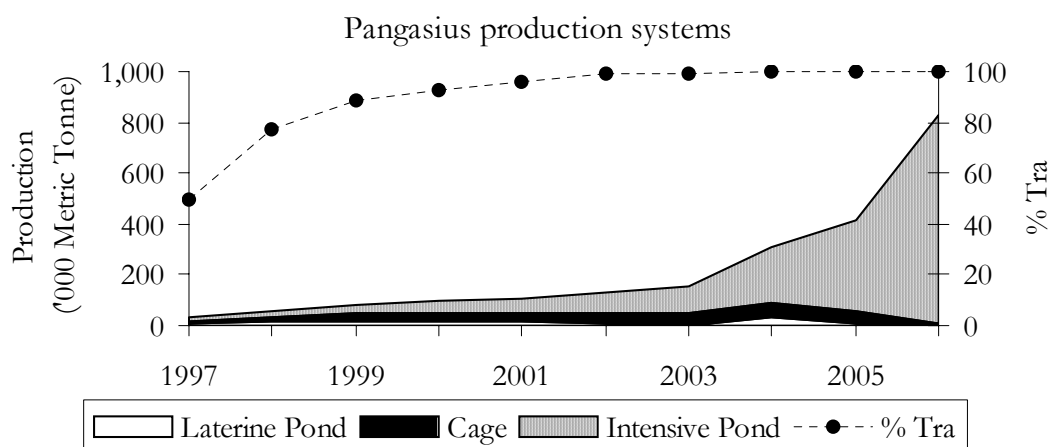


Figure 1.2: Production of pangasius in the Mekong Delta in latrine ponds, cages and intensive ponds (left Y-axis; shaded areas). Originally, both *Pangasius bocourti* (Basa) and *Pangasianodon hypophthalmus* (Tra) were produced, but the share of Tra (right Y-axis, dots) gradually increased.

Source: Dung, 2008 (11).

The increased production was achieved by producers investing in large ponds and by market chain gearing towards vertical integration.

A large share of the increased production in the past two years has been achieved through external investments in very large ponds and farms (Table 1.2). At present, so-called vertical integration is occurring, which means that fish processing companies acquire their own production facilities to make themselves less vulnerable to fluctuating prices and to negotiations with farmers for certification. As a consequence the average farm size is further increasing.

Table 1.1 The evolution of the frequency distribution of pangasius farms (%).

Year	Approximate total area (ha)	Percentage of farms by size category		
		Small (0.035 - 0.1 ha)	Medium (0.1 - 0.3 ha)	Large (> 0.3 ha)
2004	3,000	17	53	30
2007	10,000	10	30	60

Source: Based on Nhi, 2005 and Dung, 2008

Most farms keep fish at densities of 15 to 25 fish/m³ in ponds having a depth of up to 4m, and farmers are advised to refresh the water daily from 20 to 40%.

The average pond area in the two main producing provinces, An Giang and Can Tho, was 1.5 ha per farm (Table 1.2). Most farms have several ponds and some companies own several farms. The density of pangasius in ponds having a depth of 2 to 4 m is 30 to 90 kg/m² prior to harvest, which compares roughly to 15 to 25 fish/m³. Extension services recommend exchanging daily 20% of the pond's water in the first four months, and 40% during the last two months of the six-month production cycle. Farmers rely mainly on diurnal tidal fluctuations, which restrict the frequency to twice a day partial water exchange.

Table 1.2 The average size of pangasius farms and ponds in the two main producing provinces in 2007.

Province	Pond area per farm (ha)	Average pond size (ha)	Number of ponds per farm
An Giang	1.6	0.40	3.5
Can Tho	1.5	0.42	3.5

Source: Can Tho university, College of Aquaculture and Fisheries, thesis reports.

The sustainability of the sector is threatened due to the increased environmental pressure, and hampered by growing cost of input and reduced farm-gate prices for the fish. The Vietnamese government developed a Master Plan for the sector. All stakeholders can use the results of this screening LCA as a basis for more specified mitigation strategies.

Fish meal and other feed ingredients are limited resources. The price of manufactured feeds therefore nearly tripled since 2005, whereas costs of fuel and of other on-farm production costs more than doubled. This coincides with a global oversupply of pangasius fillets that reduced farm-gate prices to less than production costs for most of 2008.

The growing farm sizes increased their environmental pressure, although this factor might make the technical implementation of costly environmental measures easier. Scientists and the international press expressed concern about the environmental impact of the sector in recent years. A workshop organised by WWF in 2007 identified eight – additional – sustainability issues at farm level: (1) legal compliance, (2) social responsibility and user conflicts, (3) escapees, (4) land and water use, (5) water pollution, (6) feed management, (7) health management, (8) antibiotics and chemicals. In 2008, the Vietnamese government has developed the Master Plan 2020 to combat the environmental problems in the pangasius sector in the Mekong delta area. The plan proposed regulations on culture technique, standards on feed production and on quality of effluent water from culture ponds, and spatial planning. The current study is intended to support the implementation of this MasterPlan 2020 by screening the environmental impact of the sector. The Vietnamese government and other stakeholders can use the results of this screening as a basis for developing more specified mitigation strategies.

1.3 Set-up of the Mekong Pangasius' Environmental Impact Assessment

The EIA was a seven step process during which we interact twice with main stakeholders.

The EIA of the pangasius sector in the Mekong Delta was carried out in the seven following steps:

1. Scoping workshop with stakeholders (one day)
2. Training and project-planning with study team (two day session)
3. Data collection for inventory analysis by the study team
4. Calculation and impact assessment
5. Interpretation with MARD - Aquaculture Department
6. Stakeholder workshop
7. Reporting and communication of results.

The scoping and goal setting was done with stakeholders from the sector to build trust. The preliminary results were discussed with policy makers and stakeholders.

The scoping workshop aimed at defining the goal of the EIA, outlining the production system, and setting the system boundaries and the functional unit for this project together with the stakeholders. Therefore stakeholders from all segments of the pangasius sector were invited for a one-day workshop on 25 August in Ho Chi Minh city (see Annex A for the questions addressed). The workshop was a first step in building confidence of the stakeholders. Getting and maintaining cooperation of “key-stakeholders” is crucial, because they are the sources of data and implementers of recommendations at the same time. For the same reason, the preliminary results of the study will be communicated to the Ministry (step 5) and subsequently discussed with the stakeholders in a public workshop (step 6), before being communicated to a broader public.

The stakeholder workshop was followed by a training workshop of the study team.

At the two-day training and project-planning, the study-team discussed and exercised all 4 phases of the LCA, including the use of SimaPro, a software tool for LCA. The study-team discussed the methodology and made methodological choices to tailor the LCA to the preferences mentioned by the stakeholders and by the demanders of this study.

In the next chapter we will briefly define and discuss the methodological choices. The opinions and views of the stakeholders are integrated in sections ‘Production system’ and ‘Goal and scoping’ of the next chapter. The results of the data inventory of will be presented in chapter 3, the calculated environmental impact will be given in chapter 4 and discussed in chapter 5, using also the observations of the stakeholders, before giving conclusions and recommendations in a last chapter.

2 Methodology of the EIA pangasius Mekong Delta

The methodology specifies choices on allocation, impact categories, tools for interpretation, and data requirements. Among others the assumptions and the study's limitations will be given in section 5.1.

This chapter specifies the approach taken in the EIA of the pangasius sector in the Mekong delta. LCA is the main method used and its methodology consists of four main phases:

- Goal and Scope Definition – the product(s) or service(s) to be assessed are defined, a functional basis for comparison is chosen and the required level of detail is defined;
- Inventory Analysis – quantification of extractions and emissions, the energy and raw materials used, and emissions to the atmosphere, water and land for each process. These are combined in the process flow chart and related to the functional basis;
- Impact Assessment – the effects of the resource use and emissions generated are grouped and quantified into a limited number of impact categories which may then be weighted for importance;
- Interpretation – the results are reported in the most informative way possible and the need and opportunities to reduce the impact of the product(s) or service(s) on the environment are systematically evaluated.

This chapter specifies the methods and means used in each of these phases together with methodological and value choices, and assumptions made. All choices and assumptions are by definition made during goal and scoping. The specific choices and assumptions on the subsequent phases are for reasons of readability mentioned under the respective phases.

2.1 The product system

Independent topics of scoping are the systems description, its boundary and the functional unit to be used.

Goal and scope define unambiguously the purpose and specifications of an LCA. This is a crucial phase in LCA. If well done, the other phases are just matters of following the adopted method. Scoping basically outlines all subsequent phases in LCA according to the goal set. However, main independent topics of this phase are the system description, the system boundaries and the functional unit. A product system or life cycle goes from resource extraction, through material production, and product manufacture to product use, until waste disposal and processing. A full LCA compiles and evaluates all inputs, outputs and potential environmental impacts of each sub-system of a product system throughout its life cycle.

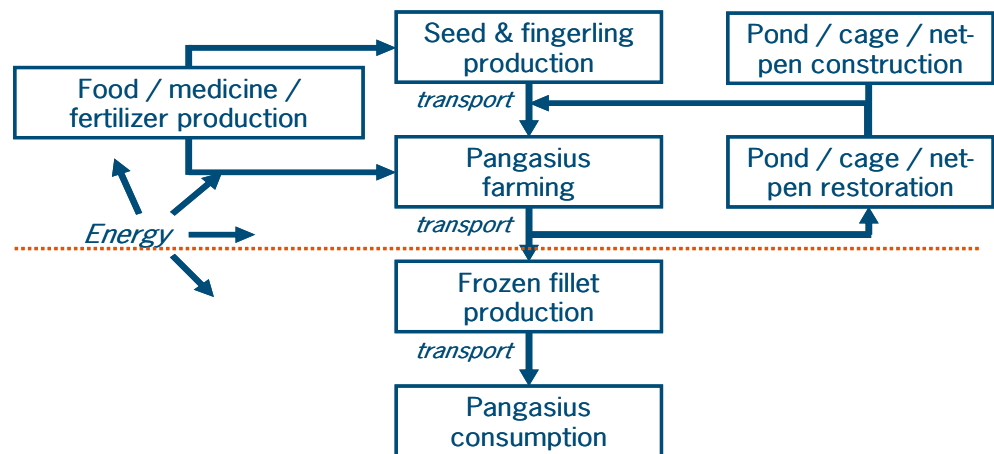
The scoping workshop confirmed that the EIA is needed because the fast growth of pangasius sector in the Mekong Delta raised:

- international concern about the environmental impact
- regional problems of safe drinking water supply
- regional concern about the sustainability of the producers' livelihoods,
- and a national desire for strategic policy making.

The stakeholders proposed to put the boundary at the farm-gate because good policies are available for the processors. The functional unit will be 1000 kg of fish (1 metric ton).

The scoping workshop resulted in a global description of the pangasius production system with its sub-systems. The stakeholders decided to restrict the product system on the output side to the farm gate, and thus to do a cradle-to-gate assessment (Figure 2.1). The representatives of the pangasius sector used three arguments to set the boundary at the farm-gate: (1) the regulations for the processing industry are well-defined, (2) the technologies for mitigation of environmental impacts by the processors are available, and (3) this process is under control of MARD/Naviquad and other authorities. Therefore also, the functional unit for this study was maintained at one metric ton (1000 kg) of fresh fish delivered to the processing industry. The consumption through the local market of fresh pangasius fish and pangasius fillets, and its environmental costs are not specifically considered as these are of minor importance compared to those of the fish export sector.

Figure 2.1:
An overview of the pangasius production system and the boundary for the Life Cycle Assessment (dotted line).



The LCA focused on ponds, on striped catfish, and on commercial feeds.

The analysis will focus on the ponds and thus exclude the production in cages, fences and nets as these systems have become relatively unimportant. As a consequence the study will treat mainly with striped catfish or *Pangasinodon hypophthalmus* (Tra) because *Pangasius bocourti* (Basa) is not cultured in ponds (Figure 1.2). The home-made feed will be excluded because this sub-system is small and difficult to quantify. The EI of the plastic bags used for feed-packaging will be included in the sub-system of feed production.

The impacts of medicine production and use are included in the LCA, and other effects of their use are stressed.

System boundaries specify which processes are included and excluded in a product system. Usually, system boundaries are set to exclude clearly irrelevant processes, but there can also be practical reasons to set system boundaries. In order to save time, stakeholders advised the researchers not to include the production of medicines in the LCA, because the quantity used is limited and the production process is located outside the Mekong Delta. However the software simply included these impacts, which was not modified during the procedures. The effects of using the medicine will be stressed.

The LCA will have a screening character using worst cases scenarios for less crucial processes, and focusing on processes that can be affected by decisions based on the LCA.

The LCA considers both the farming and the input providers, and uses physical allocation of sub-systems providing feeds.

Next to the environmental impacts included in the LCA, this EIA will address specific environmental issues that are a concern to stakeholders.

Due to the limited budget and time, the team started with a quantitative screening LCA as an intermediate approach between a qualitative/semi-quantitative and a detailed LCA. The screening LCA here covers the main processes in the life cycle up to the farm gate, and uses worst case scenarios for the less important processes and less important impact categories. A next project can elaborate these processes and categories in more detail if necessary. We focus here on the environmental changes from processes that can be affected by the decision(s) of local decision makers. This basically makes it to a consequential LCA. An attributable (or accounting) LCA would cover all processes in the product system under study and would answer the question on what environmental impact a product can be held responsible for.

The LCA will consider both so-called foreground (on-farm) processes, and background processes (e.g. input providers). Foreground processes are those on which local decision makers may take measures concerning their selection or mode of operation. All other processes, which are influenced indirectly by measures in the foreground system, are considered background processes. The requirements for quality and precision of the data for some background data are decided to be less strong (see section Inventory). This LCA focuses on detailing the foreground system as this part of the product system is under direct influence of the local decision makers. For the back-ground sub-systems (e.g. rice-bran provided by rice cropping also delivering rice, hulls and straw), the team opts to allocate based on physical and user relationships, as the economic relationship changes frequently.

As a result of the stakeholders' comments, though partly quantified in the LCA as well, specific chapters will address water quality parameters and the effects of using fish for feed on aquatic biodiversity. Next to this, the use of medicine due to fish diseases, the effect of discharged sediments, and the consequences of ponds adjacent to dikes on the flood protection and on the water flow, will be discussed. Social issues in general will not be considered as we focus on the environment; however environmental issues with social impact such as water quality and biodiversity will be stressed.

Table 2.1 Processes and issues to be assessed for the EIA pangasius MD.

Processes (within LCA)	Issues with special focus
1. Fish feed farming	1. Erosion/sedimentation
2. Pellet processing	2. Siltation & soil pollution
3. Production of lime & fertiliser	3. Change water current & storage
4. Hatchery	4. Fish disease, medicines & anti-biotic resistance
5. Pond preparation	5. Water quality
6. Fish farming	6. Aquatic ecology & biodiversity
7. Transport and power production	

2.2 Inventory analysis

The inventory analyses the product system and collects relevant inputs and outputs.

During the inventory, we analysed the product system and collected data on economic and environmental inputs and outputs for all processes within the system boundaries. The product system in this project includes all processes specified in the first column of table 2.1. The inventory or data collection was assigned to different members of the team (Annex B). The members of the study-team used a preconceived excel sheet for the data-collection (Annex G). The collected data covered the direct on-farm uses, but also included the direct uses for feed manufacturing. These data of the direct inputs and outputs for the sub-systems were encoded and summed in MS-excel. The inputs were related to the functional units and averaged by using SPSS.

Inventory data for energy, feed and other inputs were for the larger part taken from databases in SimaPro 7.1.

For modelling electricity supply, we took the Norwegian production and distribution network in EcoInvent 2.0, and adapted it to Vietnamese source distribution (see Table 2.2). Data from EcoInvent 2.0 were also used for modelling the production of feed ingredients, except for rice that were modelled separately (see Section 3.3). Data for the production of lime, chemicals in general and for transport were from ETH-ESU 96 that are incorporated in EcoInvent 2.0.

Table 2.2 Distribution of energy sources used for electricity production in VietNam (%).

Year	Source of the energy providing electricity					
	Hydro-powered	Diesel	Gas	Coal	Recycled	Imported
2004 *	20	50	12	18		
2010**	37.1	35.8	0	20.6	1.9	4.7

Reference: * Energy Information Administration, 2007; ** Long P.V.T, 2007.

For each process the sample size was based on 6 aspects of data quality.

As mentioned earlier, the requirements for the data to be collected varied according to the type and the importance of the process for the screening LCA. Goedkoop *et al.* (2006) distinguished six aspects and five categories within each aspect of data quality (see Annex C for details): (1) the reliability of the data source, (2) the completeness (percentage of flow quantified) of the data, (3-5) the representativeness (geographical / temporal / technological) of the data, and (6) the sample size required to obtain the wanted precision or variability of data values. The study team used these aspects to define the data quality required to obtain the wanted precision or variability of data values (Table 2.3).

Uncertainties in, and reproducibility and consistency of data used, will be discussed.

The report specifies where possible about uncertainty information, the reproducibility and the consistency of data collection and processing. The data provided by feed factories and farmers were presented anonymously in the report; the factories (will) received a copy of the report mentioning their letter of reference. The persons and institutes that provided data were either member of the study team or acknowledged.

Table 2.3 The requirements for the data collection of the EIA pangasius. The lower the value the higher the data requirements; descriptions of the values are given in Annex 2b.

PROCESSES	Reliability	Completeness	Temporal correlation	Geographic correlation	Further technological correlation	Sample Size
Feed Factory	2	3	3	2	1	≥ 3
Lime/Fertilizer	4	2	1	1	5	≥ 10
Hatchery	2	3	1	1	3	≥ 10
Pond Preparation	2	3	1	1	1	≥ 20
Fish production	2	3	1	1	1	≥ 20
Transport	2	2	1	2	3	≥ 20
Energy	2	2	1	1	3	≥ 20

2.3 Impact assessment

Characterisation factors are used to quantify the contribution of the inventory data to a number of impact categories: Global Warming (GW), Acidification (AC), Eutrophication (EU), Energy Use (EC), Human toxicity (HT), Freshwater ecotoxicity (FWET); and marine ecotoxicity (MAET). Resource use is included as water use. Loss of biodiversity (BD) is separately considered as aquatic and terrestrial BD.

For the impact assessment, we entered the data in SimaPro 7.1 to calculate the impact category indicators and characterisation methods selected. The inventory data will be used to quantify the following selected impact categories according the chosen impact assessment methodology:

- Global Warming according to Hauschild and Potting (2005), integrated as EDIP2003 in SimaPro 7.1;
- Acidification according to site-generic assessment from Hauschild and Potting (2005), integrated as EDIP2003 in SimaPro 7.1;
- Aquatic Eutrophication according to site-generic assessment of Guinée (2002), integrated as CML2000 in SimaPro 7.1;
- Energy Consumption by adding together primary energy uses according to standard approaches from energy analysis;
- Human toxicity, freshwater and marine aquatic ecotoxicity according to Rosenbaum *et al.* (submitted), integrated as ReCiPe in SimaPro 7.1;
- Water depletion by simple adding together water uses (Pers. com. Aubin, 2008);
- Terrestrial biodiversity loss based upon Nguyen *et al.* (2008), Kessler *et al.* (2007), Alkemade *et al.* (accepted);

Except for the last one, the selected impact categories coincide with those as proposed by Pelletier *et al.* (2007) for seafood LCAs. Inventory data for the last two were not in SimaPro 7.1 and calculated and assessed separately.

Four impact (sub-) categories from Pelletier *et al.* (2007) were excluded. Photochemical Oxidant Formation and Ozone Depletion were left out as we expected little or no impact of the catfish production system. Terrestrial Ecotoxicity was not covered because good quality impact potentials were missing (Pers. Com. Hauschild 2008). Net Primary Production was left out because this was not seen as a relevant impact category for the Mekong Delta.

Terrestrial biodiversity (BD) is evaluated as Mean Species Abundance for the terrestrial environment.

Aspects that were not within the common LCA but which we considered separately were water quality, fish catches used as fish feed, and terrestrial biodiversity. Biodiversity (BD), expressed as the BioDiversity Claim (BCD; in m²), being the loss of biodiversity was compared to that of the pristine ecosystem due to combined influence of: land use (lu), infrastructure (is), and fragmentation (fr), and integrated over total area used by the process in two steps. First we calculated the Mean Species Abundance (MSA) as $MSA_{area} = MSA_{lu} * MSA_{is} * MSA_{fr}$ as proposed by Alkemade et al. (2006), and subsequently, we calculated the $BCD_{process} = (1 - MSA_{area}) * AREA_{process}$. The MSA of original species in an ecosystem relative to their abundance in the primary vegetation (Table 2.4), as proposed by Kessler et al (2007) and Nguyen et al (2008) is in line with indicators as agreed upon in the Convention on biological Diversity (CBD), and is conceptually similar others proposed by Majer & Beeston (1996), Loh et al. (2005) and Scholes & Biggs (2005).

Table 2.4. MSA values relevant for the Mekong Delta

Secondary forest / regrowing forest	0.5
Secondary bushes / regrowing shrubs	0.4
Forest plantation / planted (exotic) forest	0.2
Agroforestry (agriculture intercropped with trees)	0.5
Extensive farming / low input agriculture	0.3
Intensive farming / high external input agriculture	0.1

The effect on aquatic biodiversity will be expressed as the FFE = fish feed equivalency.

Characterisation factors for the effect on aquatic biodiversity are not available. The effect of catching feed fish will be evaluated on a general and qualitative level: overall quantities used and the species composition for the quantities caught in the Mekong Delta. The overall quantity of fishmeal used will be expressed as feed fish equivalence (FFE).

The stakeholders asked to consider other pollutants (industry), the rivers' total carrying capacity and the variation of its' flow.

The stakeholders feel that the natural carrying capacity of the Mekong river and the South China sea is important and that this needs to be considered, e.g. through comparing the effect of the high water flow rate in the flooding season with the low flow of water in the dry season. The flow rate is on average 14,000 m³/s, but varies from 6,000 m³/s (December) to 2,000 m³/s (April) during the dry season, and reaches about 40,000 m³/s during the wet season (Koo & Lee, 2000). This high flow rate is assumed to clean the delta.

For interpretation the data are sorted by process. Results will be checked and discussed by stakeholders.

To reach conclusions and recommendations, we interpreted and checked the data. For interpretation, the data we grouped by sorting and possible ranking of impact categories. The interpretation identified significant issues by structuring the impacts by process groups. The inventory and impact assessment were evaluated on completeness, sensitivity, and consistency (Annex C.2). The preliminary results were discussed with stakeholders on May 21, 2009 in Can Tho City.

3 Life cycle inventory: data collection methods and raw data

This chapter presents the life cycle inventory data for the catfish culture, starting with the grow-out farms, the gate of the considered part of the product system, and descending to the cradle. The cradle-to-gate processes are: fish hatcheries and grow-out farms, feed production, transport, water use and energy use. Additional to the life cycle inventory data, “inventory data” needed to characterise additional environmental impacts are given for water quality, land use and biodiversity and aquatic biodiversity.

3.1 The grow-out farms

Inputs and outputs of 28 grow-out farms and of 4 hatcheries / nurseries were collected.

Through surveys at 30 grow-out farms and 4 hatcheries/nurseries we gathered data on pond area, culture periods, pond preparation, stocking, feeding use, water management, and use of other inputs such as electricity, fuel, chemicals and medicines. Staff of the Departments of Fisheries Resource Protection and Management of Can Tho City and of Vinh Long province selected the farms in the four major catfish culture areas. The survey addressed the farm owners and the completed questionnaires were checked by the local authorities of Can Tho, An Giang, Dong Thap and Vinh Long provinces after the interview. Data from 2 grow-out farms were not used for reasons of reliability or incompleteness; in size these were average farms but one applied a higher water exchange rate.

The 28 farms reached an average yield of close to 300 t/ha per crop with a mean FCR of 1.86.

The mean yield per culture period was close to 300 ton/ha/crop. Some farmers cultured catfish only once a year; the average number of culture periods was 1.4 crop/year. The average yield of the individual farms was 427 ton/ha per year (Table 3.1). The yield and feed use in Vinh Long were low because farmers reduced feed distribution due to the decreasing market prices. Most of the farmers fed pellets only. Three farmers used home-made feed in addition. Two farmers stated to use home-made feed only; but one of these two was excluded because of unreliable information. The tendency to use mainly processed feed was confirmed by Phan et al (2009). The average FCR was 1.86.

Table 3.1 Characteristics of 28 catfish farms in four provinces in the MD (mean ± standard deviation).

Item	Unit	Can Tho	Vinh Long	Dong Thap	An Giang	All farms
Number of farms	N	5	4	10	9	28
Pond area	Ha	1.5 ± 1.4	5.3 ± 3.2	4.2 ± 3.7	2.9 ± 2.2	3.4 ± 3.0
Fish production	ton ha ⁻¹ y ⁻¹	645 ± 225	79 ± 30	315 ± 218	583 ± 199	427 ± 273
Feed consumed	1000 t ha ⁻¹ y ⁻¹	1.2 ± 0.37	0.13 ± 0.05	0.56 ± 0.38	1.15 ± 0.4	0.81 ± 0.53
FCR	kg/kg	1.9 ± 0.4	1.6 ± 0.05	1.8 ± 0.16	2.0 ± 0.3	1.86 ± 0.28
Electricity use	mW t ⁻¹ fish	7 ± 7	-	31 ± 37	68 ± 37	41 ± 40
Diesel use	l t ⁻¹ fish	3 ± 3	5 ± 8	10 ± 13	1 ± 1	5 ± 9
Lime use	kg t ⁻¹ fish	7.0 ± 5.8	3 ± 1	4.2 ± 4.9	5.7 ± 7.9	5.2 ± 5.9
Chemical use	kg t ⁻¹ fish	0.033	0.073	0.13 ± 0.21	0.14 ± 0.14	0.12 ± 0.17

Table 3.2 The main chemicals used for pond preparation according to the data from 4 provinces* and from the survey of 28 farms

	% of farms applying*	Kg/crop**	g per kg fish**
Lime (CaCO ₃)	95	94,392	5.2
Zeolite (60% = SiO ₂ Al ₂ O ₃)	46	12,130	0.59
Salt (NaCl)	88	8,895	0.43
Calcium hypochloride	42	425	0.02
Benzalkonium chloride	59	82	0.004
Yuca (vegetable extract to reduce NH ₃)	-	448	0.02
Vumekong	-	400	0.02
Protestol	-	400	0.02
Charcoal	-	100	0.005
CuSO ₄	66	61	0.003
Tri Chloro Isocyanuric Acid (TCCA90)		315	0.015
Potassium permanganate	27		
Iodophores	17		
Potassium monopersulfate	11		
Various		10	

* Based on reports from the PDA of AnGiang, BenTre, DongTap, TienGiang and VinhLong, a report from RIA-2 (Loan, 200x); ** the survey done for this study.

3.1.1 On-farm inputs

For pond preparation farmers used mainly products without harmful environmental impact downstream.

Most farmers used lime and salt to prepare the grow-out ponds. They applied close to 5 kg of lime per ton fish produced, on average. The farmers used more than 1 kg/t fish of other products, mainly innocent product like salt and yuca, but also zeolite, chlorine, copper-sulphate and TCCA that might be harmful for the environment (Table 3.2).

Producers also used 0.15 kg/t fish of medicines containing antibiotics.

During grow-out, farmers used per ton of fish 0.27 kg vitamin C and another 0.33 kg of products containing vitamins, enzymes and probiotics (Table 3.3). We took life cycle data for the production of pesticides from EcoInvent 2.0 to account for the production of the chemicals mentioned in this paragraph.

Next to the substances mentioned above, producers used about 0.15 kg/t fish of medicines containing antibiotics (Table 3.3). Most medicines were mixed with the feed during 4 to 7 days to treat a variety of diseases. Mortality rates varied from 16 to 23%. Farmers confirmed to respect the period of one month between medicine application and the day of marketing the fish. Also medicines were modelled by taking life cycle data for the production of pesticides from EcoInvent 2.0.

Farms used electricity for lights, water pumping and sludge removal. Their energy consumption for electricity was 43 kWh/t fish and diesel use was 4.45 l/t fish.

Calculated average pond volume was close to 130,000 m³; daily refreshment rate was 7%. About 9,750 m³ water per ton fish was refreshed, which used 2 % of the water flowing through the Mekong river.

Water use was calculated by multiplying pond length, width and depth with the exchanges rate, the number of exchanges per month, and the number of month that water was exchanged. Most farmers refresh water every day but some only once a week. The average number of exchanges was 24 per month during 4 months, i.e. the intensive part, of the culture period. Farmers used tidal force to exchange water if their pond was next to a river or main canal (47%), and a pump if this was insufficient or when not close to a main water source (63%). The average culture volume of the 28 farms was close to 130,000 m³, and the calculated average water exchange rate was about 7 % per day. The average freshwater use of these farms was close to 3 million m³/ha per year, or 9,750 m³ per ton fish. Annually between 475,000 km³/yr (Hart et al, 2001) and 520,000 km³/yr (Thanh et al, 2004) of water passes through the two main river branches. Assuming the lowest flow of 475,000 million m³/yr, to produce one million ton of catfish about 2 % of the water from the Mekong river will be diverted through the ponds.

Table 3.3 The main chemicals and drugs used during the culture period according to the data from 4 provinces* and from the survey of 28 farms.

	% of farms applying*	kg per crop	g per kg fish
Vitamine C	61	5,605	0.27
Other vitamin complexes	17	2,331	0.11
Probiotics and enzymes	35	2,108	0.10
Doxy cycline	33	1,248	0.07
Florphenicol	77	786	0.026
Sulpha (diazine/nomide/methoxanol)	30	570	0.028
Enpro (Enrofloxacin)	67	442	0.024
Amoxilline	44	77	0.004
Kanamycine	13	30	0.002
Oxytetracycline	13	16	0.001
Colistin	14	9	0.001
Ampicilline	20		
Cephalosporins	33		
Trimethoprim	39		
Amini acids	6		
Sorbitol	5		
Beta glucan	3		

* Based on reports from the PDA of AnGiang, BenTre, DongTap, TienGiang and VinhLong, a report from RIA-2 (Loan, 200x) and the survey done for this study.

3.1.2 Discharges from the catfish farm

We distinguish two types of waste water: for daily refreshment and to discharge sludge.

A recent study distinguished two types of waste water: (1) refreshment water and (2) waste water containing sludge (Smartchoice, 2008). Waste water from refreshment or daily exchange had low concentrations of pollutants (compare Tables 3.7 and 3.8). Waste water containing sludge was pumped between twice a month and once per culture period and this type of water had a high pollutant content (Table 3.7).

Table 3.7 Characteristics of inlet water and discharge water, water of various pond types, waste water, sludge and pond sediment for aquaculture systems in SE Asia and the Mekong Delta.

	P/M	Unit	BOD	COD	TAN	NO _x	N-tot	P-tot	Source
Inlet water	10 / 12	mg/l					3.5	0.26	1
Shallow pond water	10 / 12	mg/l		13.6		0.08	7.1	1.0	1
Outlet water	9 / 3	mg/l	4.6	9.5	2.2	3.3	14.8	3.2	2
Refreshment water	4 / 5	mg/l	22	27	2.2	-	4.0	1.7	3
Waste water containing sludge	4 / 5	mg/l		1769			45.6	22.7	3

P/M = number of ponds and measurements; TAN = total ammonia Nitrogen; NO_x = NO₂ + NO₃
 Source of data: 1/ Nhan, 2007; 2/ SFS/CTU; 3/ SmartChoice.JSC – ETM, 2008.

Data on water and sludge quality came from other surveys.

The chemical composition of the pond water was obtained from an ongoing monitoring program on nine farms (Table 3.7). Data from surveys on eight farms and of four ponds were used to check and complete the data on the outflow water quality, sludge management and energy use.

Table 3.8 The average estimated pollution from effluent water of 28 catfish farms in four provinces in the MD, based on average water quality of 9 other farms in 3 provinces (gr per ton of fish).

	DO	BOD	COD	N-NH ₃ *	NO _x *	N-tot*	P-PO ₄ ³⁻ *	P-tot*
All 28 farms	59	45	93	21	30	144	7	31

* For calculations of pollution, these values were adjusted with the nutrient content in the inlet water.

Content of N, P, and COD in discharged water was corrected for quality of inlet refreshment water.

The output of N, P, COD, and TSS through refreshment water, applied in the LCA, was corrected for the nutrient content in the inlet water. The nutrient content of the pond water (N = 14.8 mg/l and P: 3.2 mg/l) was reduced with the nutrient content of the inlet water: N = 0.7 mg/l and P: 0.3 mg/l (Hart et al, 2001). Estimated nutrient loss through discharged water was 0.144 kg N and 0.031 kg P, per ton fish. Considering an FCR of 1.86, a total of 18.2 kg N/t fish from faeces was wasted to the pond; what happened to the remaining 18 kg/t fish? Also values for BOD and COD are low, but we analysed for N and P only.

Table 3.9 Predicted accumulation (ACC) of sediment and of N and P in the sediment based on the total quantity of excreta, using equations determined by Nhan, 2007 (kg ha⁻¹ yr⁻¹)

Dependent variables	Predictive equations *	kg / ha / yr	kg/ton fish
Total sediment volume (SV)	SV = 206 + 50 Excreta	916	3.05
N (N _{ACC})	N _{ACC} = 304 + 129 Excreta	2,363	7.88
P (P _{ACC})	P _{ACC} = 89 + 58 Excreta	1,063	3.54

Nhan et al, 2008

Three scenarios of water, sludge and sediment discharge were calculated next to daily refreshment: the worst case discharges sludge and sediment, the most probable case pumps sludge monthly, and best scenario uses a sedimentation pond.

The N discharge in the best, most probable and worst case were: 0.14, 2.2, 7.9 kg/t fish, respectively. While for P discharges in the best, most probable, and worst case were: 0.04, 0.2, 3.6 kg/t fish, respectively.

Only part (10 to 30%) of the solid waste will flow out of the pond when water is exchanged because most settles on the bottom of ponds where sludge and sediment build up. Part of the sediment will be mineralised in the ponds themselves through the action of their micro flora and fauna. For N we considered total-N because the quantities of N from NO₂, NO₃, and NH₃ in the sludge and sediments are not stable but vary strongly according to the availability of oxygen. Data from Thailand suggest that N and P content in sediment has a maximum and that more than 50% of P and N added to semi-intensive ponds can be lost through various processes, including leaching, infiltration, immobilisation, and mineralisation (Amara et al, 2006). The feeding level in the Mekong catfish ponds is much higher compared to these ponds in Thailand. However, more nutrients are lost through seepage than are accumulated in the sediment even in ponds with very low density after 40 days of culture (Jiménez-Montealegre et al., 2004).

Manure fed ponds are presently not commonly used anymore for pangasius culturing. It is reasonable, however, to assume that the accumulation of N and P in the sludge in those culture systems is similar for the N and P in fish faeces. Nhan (2008) observed that in manure fed ponds of the Mekong Delta the total volume of sediment and the accumulation of N and P in the sediments linearly increased with the amount of excreta applied; the excreta input explained 77.5% of the accumulation of N and P. Based on Nhan's equations we estimated the nutrient losses if all available sediments were pumped in the river: 7.9 kg N and 3.5 kg P per ton fish (Table 3.9). However, if the sediment was recovered and only the upper sludge layer was pumped into the river (Table 3.7), this discharge in the river was estimated at 2.2 kg N and 0.2 kg P per ton fish. The quantity of sediment produced in pangasius ponds was estimated at about 3 tDM/t fish (DM=dry matter).

Considering the options to use separate sedimentation ponds (Table 5.1) we present three scenarios of nutrient discharge in the river, for N: 0.14, 2.2 and 8 kg/t fish, and for P: 0.04, 0.2 and 3.6 kg/t fish. The values of other water quality parameters were used as mentioned (Table 3.8).

3.2 Hatcheries-nurseries

The densities of fish at hatcheries and nurseries were low and producers used only 0.5 % of the inputs applied on the grow-out farms. Therefore this process was not included in the LCA.

The FCR at the hatcheries/nurseries was 0.05. This is very low because until the fry-stage the catfish are raised at very low densities. They forage on natural feeds and hardly receive any pellets or home-made feed. The average size of the fingerlings stocked by the grow-out farms varied between 10 to 15 cm and the average individual weight was between 15 and 20 gram. Considering an average mortality of 20 %, during grow-out, the fry represent less than 3% of the production volume for an average final market weight of 1 kg.

The use of chemicals and drugs at the hatcheries was limited to lime, zeolite, salt, and chlorine. Though the quantity of lime and salt used for pond preparation was impressive per ton of fry: 2.7 and 0.65 kg respectively; the lime represented only 0.054 kg/t of marketed catfish,

i.e. less than 2 % of the total use of lime. The total amount applied for four hatcheries was just over 1.5 t/ha. The nurseries used 5 kg of feed per ton of marketed catfish, which was 0.5 % only of the average quantity of 1860 kg/t fish consumed during grow-out.

Considering the relative low levels of the inputs, their low impact, and moreover, the demonstrated relatively low contribution to the total of the inputs to the sector, we decided not to include the nurseries in the screening LCA.

Table 3.4. The total quantities of catfish feed produced and sold by 5 companies, their total financial turn-over, and their use of energy and water per ton feed produced.

	Feed company*					
	A	B	C	D	E	F
Production (tons/year)	192,000	72,000	60,000	105,000	35,000	
Sales (tons/year)	150,000	68,000	55,000	100,000	35,000	
Turnover (billion VND/year)	1,200	544	440	800	280	
Electricity (kWh/ton feed):	0.188	0.306	0.333	0.267	0.514	0.118
Fuel (kg/ton feed)						41
Underground water (m ³ /ton feed)	0.010	0.021	0.020	0.017	0.029	

* For reasons of confidentiality, company names are not given; individual companies will be informed on the results.

3.3 Feed composition and origin of feed ingredients.

From the over 30 companies producing feed, five provided detailed information on request.

More than 30 feed companies produce catfish feed in the Mekong Delta. Five companies provided information on the composition and total quantity of feed produced, and the total quantities of ingredients, and energy and water used (Table 3.4). Different types of feed are needed in the growth stages of catfish. These five companies also provided the average chemical composition of 6 types of feed, according to fish size (Table 3.5).

Table 3.5 Average quality of feed and DM content of some of the feed constituents, according to pellet size for different categories of striped catfish, from of 5 feed companies.

	Weight category of striped catfish (g/fish)					
	<1	1 – 5	5 – 20	20 - 200	200 – 500	>500
Pellet size (mm)	1	1.5	2.5	5	10	12
Gross energy (kcal/kg)	3300	2800	2400	2100	1800	1500
Crude protein content (% in DM)	40	35	30	26	22	18
Lipid (% in DM)	8	6	5	5	4	3
Crude fibre (% in DM)	6	6	7	7	8	8
Ash (% in DM)	16	14	12	10	10	10

Feed factories specified water and energy use, and some

Per ton of feed, the average consumption of electricity was 0.32 kWh, and ground water use was 19 litres. Only one factory reported to use fuel for the production process. On average for all feed types of these manufacturers, the dry matter (DM) content was 89%, and DM

parameters of the catfish feed. contained: non-soluble ash 12%, phosphorus 1%, and NaCl 2.5%. The average stability in water was stated to be 30 minutes, the percentage of broken pellets less than 2%, and the relation length/diameter <1.5. A low water stability of the pellets will increase the FCR and the pollution potential of the feeds.

Ingredients for catfish feed came from 14 countries from all over the globe. An average feed composition was calculated from the total quantities of ingredients used by four of the companies (Annex D.1). Three other companies gave the complete formula of ingredients used for their catfish feed (Table 3.6). Except for the rice-derived ingredients, inventory data related to the production of the ingredients or the main product from which it was derived, was taken from the EcoInvent database for animal feeds.

Table 3.6 Formula of catfish feed produced by three feed mills and the estimated average composition of four other companies in the Mekong Delta (%).

Ingredient	Countries of origin	Feed company			
		A	B,C,D,E	F	G
Fish meal	VietNam, Indonesia, India, Myanmar	12.0	12.8	8.5	26.0
Soybean meal	VietNam, India, USA, Argentina, Brazil	22.5	20.7	35.0	53.0
Rice bran	VietNam, Thailand, India	22.0	21.9	7.5	
Rice meal	VietNam, Thailand, India	10.0	10.7		
Wheat bran	China, India, Germany	12.5	13.2	15.0	3.0
Cassava/Tapioca	VietNam, China, India	19.0	18.0	12.5	13.0
Fish oil	VietNam, China	2.0	1.9		1.0
Coconut meal	Philippines			6.0	
Rape seed meal	India			8.5	
Broken rice	VietNam			7.0	
Others	China, France, India, Taiwan, USA, Swiss.	-	0.7	-	4.0

Legend: Swiss = Switzerland; Others = vitamins, minerals, anti-oxydants, inorganics.

Especially high quality feed ingredients were imported. The companies did not specify the weight of the ingredients according to country of production. MARD/DAQ estimates that 90% of the ingredients for high quality feeds, and between 40 to 50% of others are imported. Since mid 2007 until end 2008, the prices of wheat meal, soybean meal, cassava, rice bran, and fishmeal increased with 93%, 52%, 37%, 29%, 14%, respectively. Average sales price of the 12 mm pellets of catfish feed was 8000 VND/kg.

Allocation of impact from sub-systems was based on physical relation. E.g. we allocated for rice-bran 10% of the impact attributed to the For the background sub-systems (e.g. rice-bran provided by rice cropping also delivering rice, hulls and straw), the team opted to allocate based on relative weight % of the output flows, as the economic relationship changed frequently. For example for rice produced in the Mekong Delta we considered that the paddy-rice from the field is composed of (FAO, 1967):

- hull = 20%;
- rice-bran = 10%;
- rice meal (polishing) = 3%;
- broken rice = 1-17% (9%);

production of rice ○ polished rice = 50-66%.

For the broken rice, we used the figure mentioned between brackets. Thus 10 % of the environmental impacts of cropping paddy-rice was accounted for using rice-bran as feed ingredients. For using rice meal this was 3% and for broken rice 9%.

The average rice yield in the Mekong Delta was 5.5 tons/ha per one rice crop (CTU/Department of Plant Science). The following inputs were used per crop of rice:

- artificial fertilizer: 95 kg N, 55 kg P, and 46 kg K per ha;
- diesel use: 20 kg/ha;
- pesticides (inorganic chemicals): 2 kg/ha/crop.

In the Mekong Delta rice is cropped two or three times a year on mostly irrigated fields.

3.4 Transport in the production process.

Average distances and fuel use for transport by sea and by road were implemented.

All visited factories were roughly located at 60 km from the main harbour in Ho Chi Minh city. For the marine transport we assumed an average distance from the main port of the exporting countries to Ho Chi Minh City' harbour; these were different for the various ingredients. The average weight of the containers used for transport from the port to the factories was 25 tonnes. This transport was assumed to be done by 28t trucks with an average fuel consumption and 40% use efficiency. In reality quite some of this transport was done by boat. The distance from fields in the Mekong delta to the companies for the transport of ingredients (e.g. tapioca, rice bran, broken rice...) was estimated at 100 km. This transport was assumed to be done by 16t trucks with an average fuel consumption and 40% use efficiency. The average fuel consumption and use efficiency of the trucks were taken from EcoInvent 2.0.

Transport distance of inputs was estimated at 100 km.

The transport of feed and other inputs from the distributor to the farms was done either by boat or motorbike. The distance was estimated at 100 km. Since life cycle inventory data for transport by motorbike and boat of the Vietnamese size were not available, we therefore assumed transport to be done by 16t trucks with an average fuel consumption and 40% use efficiency. The transport of the fish from farm to the processing plant, either done by boat or motorised vehicle or both, is outside the system boundaries of this LCA; thus, was not accounted.

3.5 Energy production.

Farms and factories used both electricity and fuel. We made an educated assumption on the electricity production with regard to the energy sources and the

Life cycle inventory data for the production of diesel used on-farm and in the feed factory were taken from EcoInvent 2.0.

For modelling electricity supply, we took the Norwegian production and distribution network in EcoInvent 2.0, and adapted it to Vietnamese source distribution. Two references provided different data on the source of energy used to generate electricity in Vietnam (Table 2.2). We applied the distribution of national energy sources from 2004 to the pangasius production sector in the Mekong Delta for the

distribution network. following reasons. We assumed that all imported electricity originated from hydro-powered plants. Moreover we assumed that natural gas would become an important energy source in the Mekong Delta after the start-up of the new power plant in Ca Mau (My An, 2009), and that diesel would remain important for the other existing or new plants in the Mekong Delta.

3.6 Land use and terrestrial biodiversity

Land-use changes since 2000 on river banks, outside or inside the flood protected area will be identified and classified for MSA type and sensitivity to erosion.

The effect of change in land use will only be considered for the fishponds created since 2000 in non-agricultural land in the Mekong Delta. We made three assumptions: (1) before the boom of pangasius culture mostly shallow ponds were constructed in existing rice fields; (2) for both the mono-cultured rice and the intensive fishponds the MSA (Mean Species Abundance) was 0.1; (3) there no replacement of intensive rice culture to new areas with a higher MSA due to the transformation of agriculture land in fishponds. In fact, the Mekong Delta has produced a large surplus of rice and since 1996 farmers had been looking for land-uses with a higher financial margin than rice production (Bosma et al, 2006).

Most recent GIS map with catfish farms from 2007, and maps with other land uses from 2000 and 2005 were acquired. The map of the catfish farm location in 2007 was superimposed on the land-use maps of 2000 in ArcView®. The catfish farms build after 2000 in non-agriculture land were identified in four categories: built inside or outside flood protection dike; built or not on the erosion sensitive riverbank. We attributed an MSA of 0.45 to the flooding areas around canals and rivers covered with re-grown of shrubs and bushes outside the flood protection dike. In the regions where catfish farming was located in 2000 there was no land use such as forest with a $MSA > 0.45$. The area of the ponds located outside the flood protection dike could also be accounted as reduced water storage capacity. The area of ponds built inside and straight adjacent to the flood protection dikes was counted as the area of ponds endangering protection dikes and increasing the risk of their erosion and of flooding if located in areas classified as erosion sensitive (Le Man Hung et al, 2006) .

3.7 Use of aquatic resources

The inventory of using aquatic resources will focus on catching fish for feed.

The use of aquatic resources for pangasius farming and its effect on aquatic biodiversity has two aspects. The danger of selection and breeding for fast growth on the resilience of the original species if the selected strains escape, is difficult to measure or estimate and will not be discussed. We will focus on the effect of catching fish for feed.

Characterisation factors for the effect on aquatic biodiversity are

The effect of catching feed fish will be evaluated on a general level: overall quantities used and the species composition for the quantities caught in the Mekong Delta. The overall quantity of fishmeal used will be expressed as feed fish equivalence (FFE). The ratio of live fish to fish meal is about 4.5 (Boyd et al, 2007). It takes 10 to 20 kg live fish to

not available and this impact will be described and expressed as the FFE = fish feed equivalency.

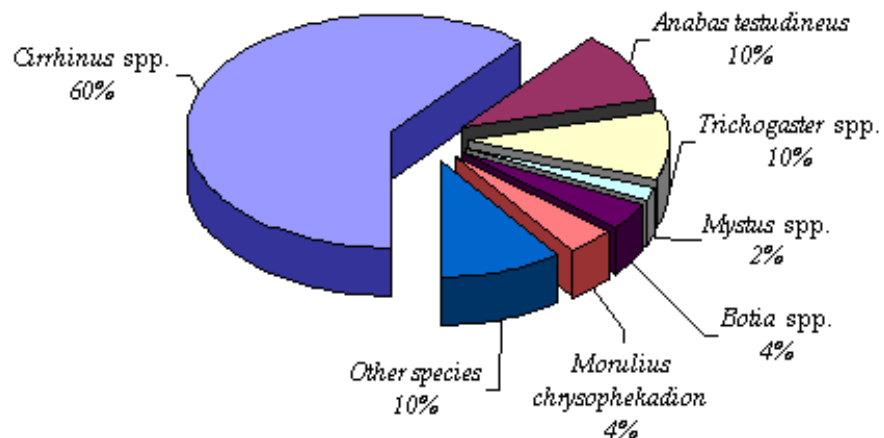
produce a kilogram of fish oil, but the quantity varies greatly by species and season (Tacon et al., 2006). However, “fish-oil ratios” and feed-fish equivalences that include oil are more difficult to calculate and interpret than those for fish meal because of the large variation in fish oil yield and the history of fish oil as a by-product of fish meal production. Therefore fishoil will be accounted as fishmeal in the calculation of the FFE: $FFE = FCR \times \% \text{ Fish (meal +oil) in feed} \times 4.5$.

Fishmeal and fishoil come from various Asian countries.

The fishmeal used by the factories that provided information originated from VietNam, Indonesia, India and Myanmar; and the fishoil from China and VietNam. The fishmeal and fishoil originating from VietNam were either processed residues from the fish processing industry, or trash-fish from large fishing boats, or were special catches for feed processing. These last competed with the demand of the processors of fermented fish sauce.

The average proportion of fish meal and fish oil incorporated in the feed was estimated at 14.8 and 1.2 %. For an average feed conversion ratio of 1.86 and a production of 1.2 million tonnes the total use will be about 331,000 tons of fish meal and 27,000 tons of fish oil for the Mekong Delta.

Figure 3.1. Species composition of fresh water fish (by weight) fed to *Pangasius spp.* in An Giang and Dong Thap province in 2005 (Vu & Bach, 2005).



The fish for feed comes from inland and marine catches. If fully grown *Selaroides leptolepsis* and some species of genera *Decapterus* and *Cynoglossus* might be attractive for human consumption

Fish for fish-feed is caught both in fresh and marine water (Vu & Bach, 2005). The size of the species varies from 2 to 11 cm for fresh water species (Figure 3.1) and from 3 to 30 cm for marine species (Figure 3.2). Only trash-fish from marine catches contains species that are interesting for human consumption e.g. *Sardinella sps*, *Selaroides leptolepsis*, *Decapterus sps*, and *Cynoglossus sps*. The marketed size (6-16cm) and the price paid for *Sardinella sps* are about equal when used to process human food or aquafeeds. The equally sized *Selaroides leptolepsis* (5-12 cm) catches a much higher market price for human consumption. Some species of the genera *Decapterus* (7-19 cm) and *Cynoglossus* (7-15 cm) might grow out to larger sized fish attractive for human consumption.

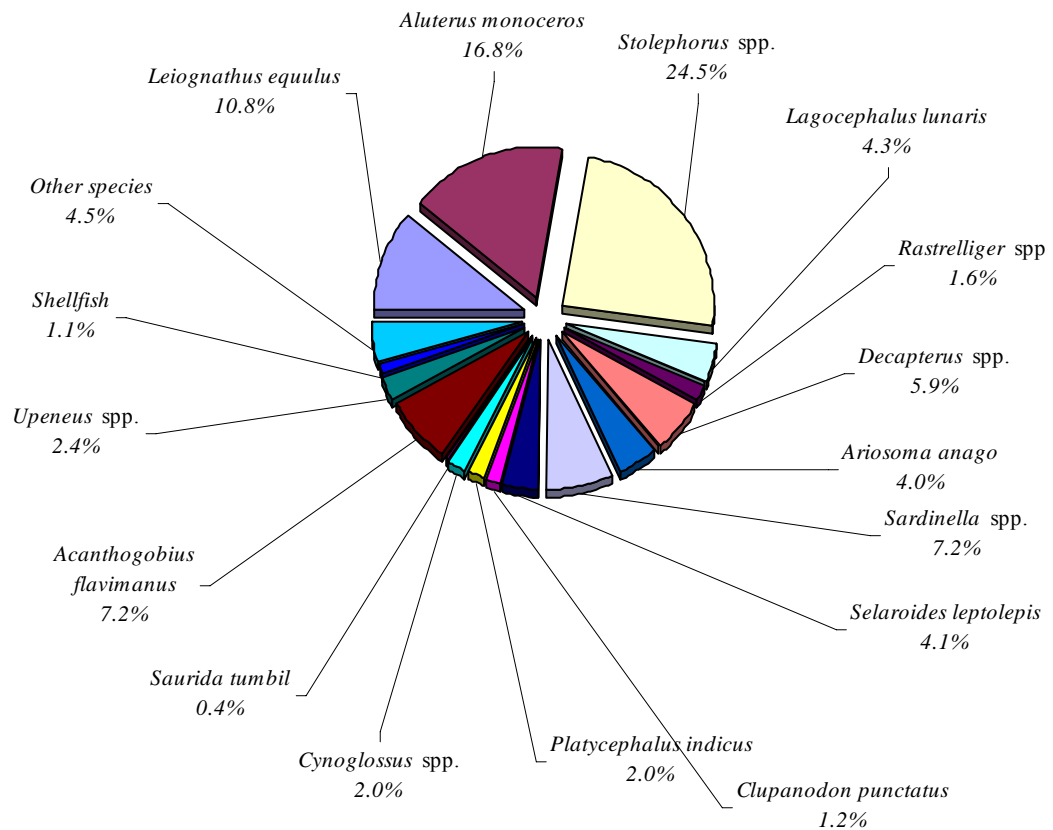


Figure 3.2. Species composition of marine fish (by weight) fed to a.o. *Pangasius* spp. in An Giang and Dong Thap province in 2005 (source: Vu & Bach, 2005).

4 Life cycle impact assessment

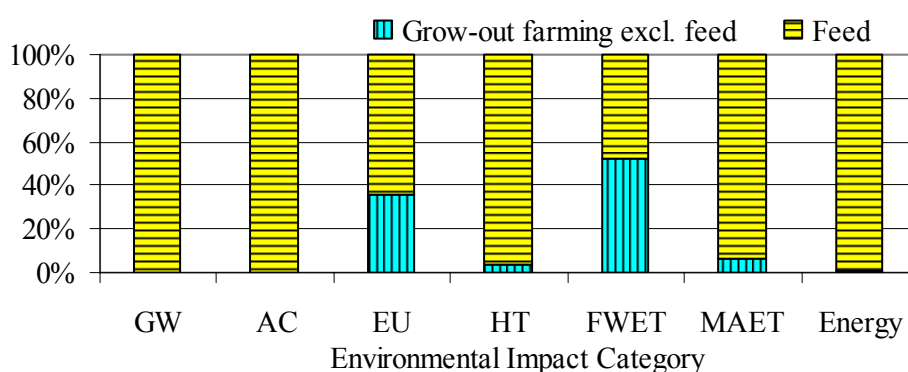
Special LCA software was used to assess all stages of the product lifecycle.

The impact assessment aims to understand and evaluate the magnitude and significance of the potential environmental impact of a product system for each process and to each of the selected impact categories. Thereto the environmental impact of pangasius culture was analysed for the total production, and in more detail for the differences between the feed sources. The assessment of the various impact categories was based on the inventory table as described in Chapter 3 and summarized in Annex F. This impact assessment was performed in SimaPro software which allowed us to assess all stages of the life cycle up to the required detail (e.g. Figure 4.2).

Figure 4.1.

The average contribution to eight environmental impact categories from average feed production and from all other processes involved in the pangasius farming .

GW = Global warming;
AC = Acidification;
EU = Eutrophication;
HT=Human Toxicity;
MAET=Marine Ecotoxicity;
FWET = Fresh water Ecotoxicity.



4.1 Life cycle impact assessment

Feed contributes most to the EI of the pangasius farms; the contribution varies for the impact categories. Processes taking place in Vietnam contributed to eutrophication and toxicity; the contribution to HT is small but zeolite does more harm than lime and salt.

The life cycle inventory data from Chapter 3 were used to perform a life cycle impact assessment as specified in Chapter 2. Table 4.1 quantifies the total cradle-to-gate contribution of pangasius to the selected impact categories. Figure 4.1 shows the share of two parts of the pangasius product system to the total: average feed production and all other processes involved in pangasius farming. Except for eutrophication and fresh water ecotoxicity, the fish feed dominated for the selected impact categories by contributing for 90% or more to the total impact. The contribution to eutrophication and fresh water ecotoxicity, during on-farm grow-out came from the waste discharge mainly.

The main contribution to human toxicity came from the emissions during production and use of pesticides and fertiliser to produce feed ingredients. The contribution from farming to human toxicity was small, but zeolite contributed more than lime. The contribution to any impact category of medicines and chemicals other than zeolite, lime and salt was limited. The majority of the products used for pond preparation had their environmental impact through the production and transport mainly. With the exception of chlorines and zeolite, the applied chemicals, probiotics, enzymes and vitamins did not appear in the used databases with characterisation factors for toxicity (Rosenbaum et al, 2009).

Table 4.1 The environmental impact for selected impact categories of producing one ton of striped catfish in the Mekong Delta assuming an average feed composition.

	GW	AC	EU	HT	FWET	MAET	Energy
Unit	ton CO ₂	m ²	kg PO ₄ ³⁻ eq	kg DB eq	kg DB eq	kg DB eq	GJ
Value	8.93	459	40	4296	1.34	2513	13.2

DB eq. = 1,4 Dichloro Benzene.

The feeds varied strongly in impact due to ingredients and their origin; the origin is important for the impact on marine ecotoxicity especially.

We looked closer into feed production and use, more in particularly to commercial food as this was used by more than 90% of the farms (see 3.1). The feeds contributed to various toxicities mainly through the production and transport of their ingredients. Table 4.2 illustrates that the environmental impact of striped catfish differed between the commercial feeds especially for global warming, acidification, and eutrophication. These differences could be attributed to the feed composition and the origin of the feed ingredients. This is relevant information because it indicates that farmers can influence the environmental performance of their fish by the feed used.

Table 4.2 The effect of feed composition on the environmental impact for relevant impact categories, according to ReCiPe, 2008 of producing of 1 ton striped catfish, assuming identical FCRs.

Impact category	GW	EU	HT	MAET	Energy depletion
Feed source \ Unit	kg CO ₂	kg PO ₄ ³⁻ eq	kg DB eq	kg DB eq	kg oil eq
A	6.54	33.4	2.36	1.46	3.5
B – E	8.89	31.5	2.22	1.26	3.9
F	8.78	29.6	2.19	1.27	3.9
G	2.85	14.3	2.38	1.51	2.2

For abbreviations see Table 4.1 and Figure 4.1.

Among feed ingredients rice bran dominated for GW and AC, and wheatbran for EU.

We analysed in more detail the production processes for the average feed, because feed was, overall, the main contributor to the environmental impacts (Figure 4.2). The contribution of rice bran dominated for global warming, and acidification due to the quantity incorporated. Eutrophication gave a negative value as soybean was used as substitute for fishmeal.

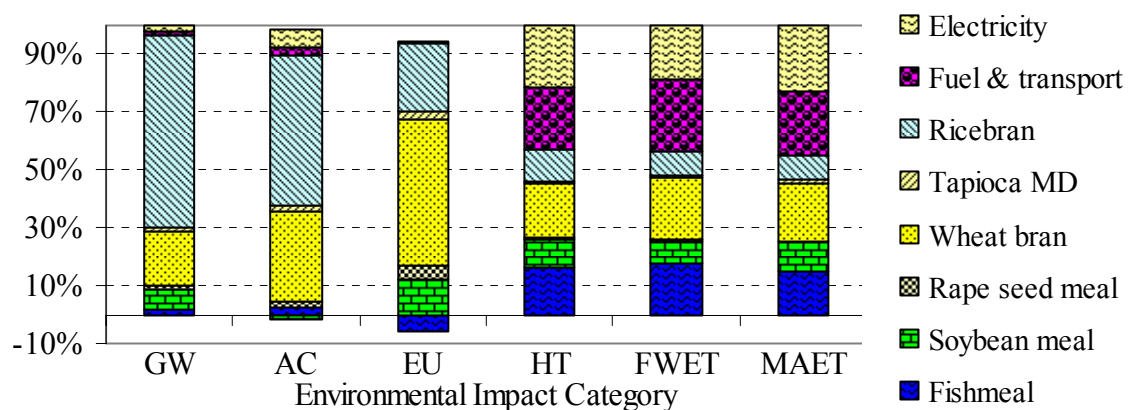


Figure 4.2. The distribution of the contribution to six environmental impact categories of the inputs to the feed production process for the average feed. For abbreviations see Figure 4.1

Energy and transport dominated toxicity categories, next to the production of fishmeal.

The high contribution to the three toxicity impact categories came from the transport of feed, from the electricity for the production of feed and from the production of fishmeal (Figure 4.2). Wheat bran dominated for eutrophication especially compared to its relative modest share in total feed (Figure 4.3a). Detailed analysis showed that this domination was due mainly to its production and transport mainly. The contribution to human, fresh water and marine toxicity from the feed came mainly from the transport (both marine and land) and from the generation of electricity needed for the process (Figure 4.3b).

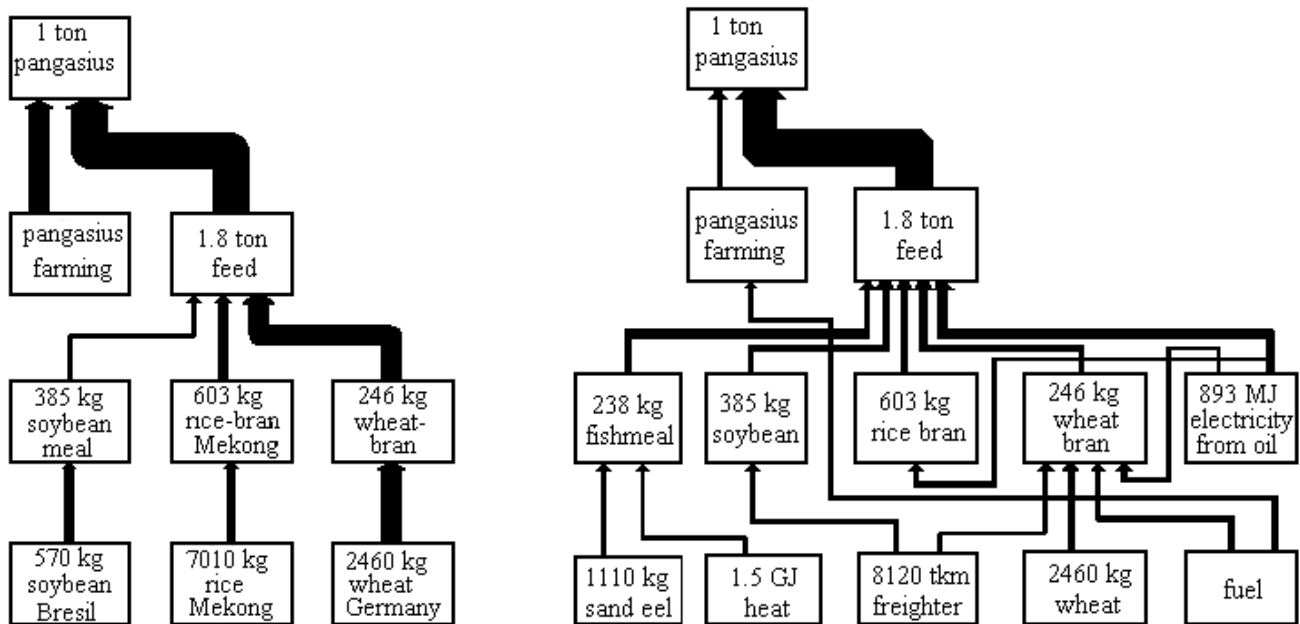


Figure 4.3a (left). The processes and substances in the pangasius production system contributing more than 11% (cut-off value) to the aquatic eutrophication.

Figure 4.3b (right). The processes and substances in the pangasius production system contributing more than 6.3% (cut-off value) to the marine ecotoxicity.

The thickness of the lines represents the share of substances or processes in the contribution to the impact.

4.2 Water use and other effects on water.

Water use was high but most restored as green water.

Both feed processors and striped catfish producers used two types of water: ground water and surface water. The water withdrawal can (1) be consumed in the production process and thus lost for other production processes, or (2) become available for other processes if not polluted. For feed processing only (excluding water use during agriculture thus), the ground water withdrawal was 19 litres or 0,02 m³ per ton of feed. This was on average 37 litres or 0.04 m³ per ton of fish which we considered consumed water. Surface water withdrawal by feed producers was infinitely small compared to the withdrawal by fish producers. The water withdrawal for fish production in ponds was close to 9,750 m³/t fish, but most of this water was restored. The net water consumption in the ponds came from losses through evaporation and infiltration (vertical percolation plus lateral seepage). If these losses were considered to be green water, inland aquaculture's freshwater consumption was estimated

Real water use was limited to 3m³/kg fish which was lower than that used for most animal proteins.

at 3,100 m³/ton fish for ponds producing 2.3 t/ha per year (Verdegem & Bosma, 2009). For ponds producing 420 t/ha per year this would be close to 180 m³/ton, provided the discharged water is harmless. The water pollution is accounted for through a.o. eutrophication and fresh water ecotoxicity in the LCA.

The total feed-associated freshwater consumption of catfish species was estimated at 2.8 m³/kg ingredient for a FCR of 1.5 (Verdegem & Bosma, 2009). For a FCR of 1.86 this resumes to 3472 m³/t of fish. Thus the total water consumed to produce striped catfish in the Mekong Delta can be estimated at about 3472 + 180 + 0.04 = 3650 m³/t, which is higher than what is needed to produce milk and egg (2700 m³/t), but lower than other animal proteins (Verdegem et al, 2006).

Contribution to the total suspended solids of sludge from Pangasius culture was limited as sedimentation, mineralisation, and infiltration occurs in the ponds.

The survey of 30 catfish farms did not measure the total suspended solids (TSS). A smaller sample of four farms in Smartchoice (2008) found a TSS of 42 mg/l and confirmed the other data on water quality of the pond. The TSS in the river¹ was on average 216 mg/l (Kummu & Varis, 2007), but tended to decrease downstream. In Cau Doc and Can Tho, TSS varied from 0 to 175, with an average of close to 50 mg/l (Hart et al, 2001, section 5.1 and Annex E.2). This last value is still higher than in the pond where sedimentation occurs. This is also evident through the relatively low COD of the output water: the organic matter accumulates at the pond bottom. The superficial water refreshment of the pangasius ponds does not contribute to an increase of TSS and COD concentration in the Mekong River.

Table 4.3 The contribution of pangasius farming to the content in the Mekong river of TSS, COD, total N and total P, assuming a total flow of 475,000 km³/yr.

	Average in Mekong river water		Contribution from pangasius ponds			
	mg/l	t/yr	Worse case		Most probable case*	
			t/yr	%	t/yr	%
TSS	216 **	102,600,000	-	-	9,082	0.01
COD	5.5 **	2,612,500	-	-	7,983	0.31
total N	0.7 ***	332,500	8,020	2.41	2,104	0.63
total P	0.2***	95,000	3,577	3.77	202	0.21

* assuming 20cm of sludge is pumped twice per culture period (Smartchoice, 2008);

** Smartchoice, 2008 (see Table 5.1);

*** Hart et al, 2001 (see annex E.2)

N discharge from pangasius ponds was probably close to 2% of total N in river.

The worse case scenario discharges to the Mekong river for N and P were 2.4% and 3.7% respectively of the total N-content in the river. In a sample of 35 farms in one province Pham et al (2008) found that in wet season more farmers (>60%) pump sludge in the river than during dry season (<30%). In four provinces, the larger random sample from Phan et al (2009) found that on average 82% of the farmers discharge the sludge. These data support the assumption that the most probable estimations were close to 2% and 3% for N and P, respectively (Table 4.3).

¹ The content of TSS was close to double before the construction of the large dams upstream.

4.3 Effect of use of pond construction on other land uses.

Close to 6000 ha of pangasius culture area is constructed inside the river banks but occupies less than 0.5% of the flooding area.

Total area of the Mekong Delta is close to 38,000 km². The land use for Pangasius farming in the Mekong Delta is estimated at 6,000 ha or 60 km². This is less than 0.2% of the total area of the Mekong Delta. Pangasius ponds are usually built in inundated areas near the bank of large rivers for the convenience of water exchange and transportation. As such they occupy water storage capacity during flooding. Flooding occurs annually in a large area of Viet Nam's Mekong Delta. The flooded area varies from approximately 1.2 to 1.8 million ha in respectively low and high flood years; flooding lasts from two to six months with water depths between 0.5 and 4.0 m (Hien, 1998). In a worst case scenario, the catfish culture area of 6,000 ha occupies less than 0.5% of the flooding area of the Mekong Delta.

Less than 0.5 % of the culture area increases erosion risk along 3.5 km of flood protection dikes in two communes.

The length of river bank sensitive to erosion was estimated at 118.5 km in 45 communes along the Lower Mekong Delta (Hung et al. 2006). In 2007, pangasius was cultured in ponds along the flood protection dike in two of these communes only: Vinh Truong commune (An Phu district, An Giang province) and Binh Hoa Phuoc commune (Long Ho district, Vinh Long province). The ponds in these districts covered 20 ha on 2 km of river bank in Vinh Truong and 12 ha on 1.2 km of river bank in Binh Hoa Phuoc. In total only 32 ha from over 6,000 ha or about 0.5% of the pangasius culture area, is located along river banks sensitive to erosion. This equals to a total length of 3.2 km that is exposed to an increasing erosion risk of the flood protection dikes.

4.4 Effect on biodiversity

The average FFE of seven feeds is 1.34, and for most feeds the use of fish for feed is inefficient. A small fraction of the fish caught might be attractive for humans.

The average FFE (feed fish equivalence), the indicator used for aquatic biodiversity was 1.34, but the extremes in our sample of seven companies were 0.7 and 2.6. On average the quantity of fish fed was higher than the quantity produced, but feeds with a low FFE can be produced. This indicated that the indirect effect on aquatic biodiversity can be reduced.

Most of the fish caught for fish feed in Vietnam is not attractive for direct human consumption. *Selaroides letolepsis* catches a better price and some species of the genera *Decapterus* and *Cynoglossus* might grow out to larger sized fish but the interesting species were not identified.

The reduction of terrestrial biodiversity is estimated at 0.24 %.

Less than 1 km² of ponds was constructed in flood protected areas and all were located in former rice fields. Based on the assumptions, the biodiversity change (BDC) due to pangasius farming in flood protected areas is zero. About 60 km² of ponds was built on the river banks in the flooding areas, either covered secondary bushes and forest or used for extensive farming; the average MSA before pond construction can be estimated at 0.4. The total BDC due to pangasius farming is $(0.4-0.1)*60 = 18$. Assuming an average MSA of 0.2 for the Mekong Delta covering 38,000 km² the BDC due to the sector represents 0.24 %.

4.5 Toxicity

The medicine use is relatively high but its impact light. If the waiting period of one month before processing is respected most used medicines are harmless.

For the used medicines characterisation factors are not available in EcoInvent. We applied the environmental impacts for unspecified pesticides to the medicines as was done for the pesticides used in the Mekong Delta for rice cropping. The environmental impact of using medicines

Some of the medicines administrated on the fish were also used as human medicine. Their use may contribute to antibiotic resistance in micro-organisms causing diseases in animals and humans; therefore, the residue level after slaughtering should not exceed the maximum authorised residue level (MRL) given in Annex I, II or III of EU regulation 2377/90/EC for the indicated species. If the waiting period of one month before processing is respected, this risk is limited. However if the mentioned antimicrobials (d)oxytetracyclines, enrofloxacin, sulpha-based medicines, florfenicol, amoxicilline and kanamycin, are used shortly before processing the MRL for those substances might be exceeded (Table 4.5). We suspect that Clorphenicol refers to chloramphenicol which should not be used in animals producing human food.

Table: 4.5 The medicines (product name) used on 24 catfish farms in the Mekong Delta, with the name of active substance*, and the maximum residue level (MRL**) for meat.

Product	Active substance	mg/t fish used	MRL ($\mu\text{g}/\text{kg}$) / remarks ***
Doxy/oxy/tetra	Doxy - / Oxytetra- cyclin	62	100
Enpro	Enrofloxacin	21	35
Sulpha -	diazine/nomide/methoxanol	28	100
Florfenicol	Florfenicol	26	1000 till 1/7/01
Clophenicol	Chloramphenicol (?)	8	Not to be used in food-producing animals
Amox	Amoxicilline	4	50
Kanamycin	Kanamycin	1.5	100
Colestine	Colistin	0.9	150
Trimesul	Trimetoprim/sulfa ?		50
Lavetrisol	(Levamisol ??)		10
Praziquantel	praziquantel		no MRL needed

* Some products were not registered (.g. Cotrim) and whether or not they contain medicine should be checked locally. ** The CVMP of the EC advices to respect for minor species like fish: 1.5x an existing MRL of an animal husbandry species ; *** MRL's are only given to substances, evaluated positively on safety for humans , to be used in food producing animals; Substances that require no MRL are found in Annex II of Regulation 2377/90/EC.; courtesy Dr Max Siemelink, LNV, The Hague

Farmers' information on medicines seems subjective and uniform advice on GMP is urgent.

The use of the type of products for pond preparation and diseases treatment varied per region. This might be caused by subjective advices of the distribution network. It may be expected that the program on Good Management Practices (GMP) of RIA-2, CTU, and NACA, funded by the Australian government, will improve the communication on medicine use and provide more uniform information. A pilot program was started in 2006 and the program was expanded in 2008.

5 Interpretation

The following section discusses the limitations and uncertainties of this screening LCA. The next three sections discuss the life cycle impacts and present options to manage the impacts on water quality, land use and biodiversity. The responsibility for mitigating or reducing the impacts are shared but distributed over the various stakeholders.

5.1 Limitations and uncertainties

The FCRs of the farms were not related to a specific feed but to an average as data on only a limited number of feeds were available.

The environmental impact of the pangasius sector comes mainly from the feed ingredients. The impact from feed does predominantly take place outside Vietnam through the production at locations worldwide and the marine transport. The inventory data for feed production mainly came from literature (EcoInvent 2.0) and their applicability to this study is not clear. However, as feed is dominant for most impact categories, also in other LCA studies, the results of this study remain valid.

The FCR of each individual farm was calculated with the information provided. However this FCR could not be related to a specific type of feed. We could not dispose of the composition of the feeds from all companies; so we calculated farming impacts with the average composition of all available feeds. We did separate the calculation with the feeds with known composition but these were applied in general and not specifically to the farm that used this feed. Whether or not the use of specific data would attenuate or accentuate the environmental impact is not sure for the moment.

In the model, we considered 100% of the high quality and 50% of the low quality ingredients to be imported. In reality, these figures were 90% and 40 to 50% respectively.

Scenarios of nutrient outputs were calculated considering three assumptions: farmers use a high output; pond water quality data of samples apply to the 28 farms; the used equations of manure-fertilised ponds apply to the intensively fed pangasius ponds.

The nutrient outputs of the 28 ponds were based on the estimated quantity of water they discharged daily and the average nutrient content of outlet water for nine other ponds, and on the estimated composition of the sludge remaining in the pond at the end of the production cycle. The individual variation in feed source of the farmers was thus not accounted for; sample collection and especially the related laboratory analysis are costly and time consuming as two production cycles running over more than 1 year should be monitored. As this report was expected to be produced within one year, we were compelled to use secondary data.

The calculation of the composition of the remaining sludge was based on ponds fertilised with manure for other species with much lower densities (Nhan, 2007). The estimated total amount of sediments calculated with Nhan's equations is three times higher (3 t/ton of fish) than the amount observed by Truong (2008). It might well be that the worst case scenario is an overestimation of the nutrient discharge.

Water withdrawal from the river was

We assumed that pumps used for daily water refreshment have an inlet close to the water surface. If a deep inlet is used the environmental

calculated; if other calculations are considered the estimated withdrawal of 2% would be reached in 2009

The reported electricity consumption of 28 farms is much lower than the calculated use of four other farms.

impact from pond production was underestimated.

The total water withdrawal of close to 9,750 m³ per ton and 2% for one million tons of pangasius was calculated from a sample of 28 farms. Considering a pond depth of 3.5m and the advised exchanged rate, Phan et al (2009), estimated the withdrawal at 6,400 m³ per ton in 2007, or at 1.35% for 1.2 million ton fish. If 6,400 m³/ton is more realistic, the 2 % which will be reached with a production level of 1.5 million ton/yr as planned for 2009.

Based on the information from 28 farms we considered on-farm electricity use at 43 kWh/t fish. A survey on four farms in An Giang calculated the electricity consumption at 217 mWh/ha per crop. These farms hardly used the tide for daily water exchange and also pumped the sludge twice during the production cycle. Assuming a harvest of 300 t/ha per crop the electricity use would be more than 700 kWh/t fish, 18-fold the figure from the 28 farms. Over 60% of the 28 farms used pumping for water exchange but less frequently than the four in the other survey. The figure for the 28 farms is based on effective energy consumption. Either, the calculation for the four farms overestimated electricity use or both samples were not representative; in this last case the applied level of electricity use might be too low.

5.2 Environmental impacts of feed and options for reduction

Local hotspots were the production and transport of feed and the pond' effluents.

The methane emission from deep ponds needs to be specified.

The impact on most categories is not limited to Vietnam.

Feed with a lower FCR would make a difference if farmers use them.

The impact on marine ecotoxicity can be reduced by producing feed ingredients in the Mekong delta. Feed

The main impact taking place within Vietnam varied per impact category; only the main contributions to eutrophication and fresh water ecotoxicity were related to the pond's culture practices. The local hotspots were the production and transport of feed and the discharge of sludge in the Mekong river. The discharge was relatively small compared to the total content in the river and smaller or equal to other sectors.

The emission of methane from the pond was based on data from the rice field. However, the conditions at the pond' bottom are more anoxic and the methane production might be higher if not absorbed in the water column. Research is needed to quantify the methane production from the deep pangasius ponds.

Feed companies have a large responsibility in decreasing the environmental impact for most of the categories as they decide on feed origin and composition. The feed origin determines largely the marine ecotoxicity, and a local production of feed ingredients could reduce the environmental impact. The feed composition determines the FCR as well as the dependency on fish meal and fish oil and thus the FFE.

The FCR of most feeds is relatively high (1.86 on average). The best value reached by one of the 28 farmers was 1.55, while stakeholders claim that an FCR of 1.2 can be achieved by adjusting feed quality and composition. To achieve such FCR, the feed companies need to adjust the composition of their product, and the farmers need to be awarded for using these better feeds. Farmers will use better feeds if the cost/benefit ratio improves. According to the stakeholders, the FCR should be given

companies can also mitigate impacts by replacing fishmeal and improving the water stability of feed and faeces.

for feed of different fish sizes. In general, they think the FCR was better five years ago. Due to the huge demand and farmers' focus on low price, the feed quality decreased. The FCR can only improve if the farm-gate price of pangasius increases.

The feed companies already consider the water stability of the pellets in terms of feed composition to reduce the losses due to falling apart. They could consider also the water stability and relative weight of the fish faeces in their feed composition. A high water stability of the faeces and a specific weight >1 would increase the quantity of nutrients recovered in the sludge; thus, decrease the quantity of nutrients discharged in the water if the sludge is deposited on land.

The inclusion of processing in the EIA might double the impact on water use and on eutrophication.

The fish processing industry and retailing were excluded from this screening LCA. The LCA of the shrimp sector in Thailand did include fish processing industry (Rattanawan, 2005). This study showed that its contribution to water use and eutrophication was important. During shrimp processing, water use was 1.4 times the volume used for pangasius culture, and nutrient discharge was 20% for N (0.4 cc 2.1 g/t fish) but more than double for P (0.5 cc 0.2 g/t fish), when considering the most probable scenario for pangasius culture (Annex D.2).

We also excluded the hatchery and nursery stage on the basis of its negligible use of inputs compared to use of the similar inputs in grow-out. Other LCA studies of aquaculture a.o. from shrimp in Thailand (Rattanawan, 2005) and pangasius in Indonesia (Aubin, personal communication) confirm a low environmental impact during the hatchery and nursery stages. The relative and absolute low impact of the hatchery/nursery stage thus justifies our focus on the grow-out process.

Table 5.1 Water quality parameters of daily water and monthly sludge discharge, and of the daily effluent of a sedimentation pond with water plants, and the Vietnamese standard (TCVN 5942-1995 col. B) for TSS and BOD in effluents on surface water (mg/l).

Parameters	Outlet water from refreshment	Waste water containing sludge	Effluent of sedimentation pond	Standard*
TSS	42	6497	47	80
COD	27	1769		
BOD ₅	22	-	15	25
N total	4.0	45,6	6.1	-
P total	1.7	22,7	0.58	-

Source: SMARTCHOICE – ETM, 2008

5.3 Sludge and water management

According to Hart et al (2001), the contribution to the river's concentration in nutrients and suspended solids would be 5 times higher during the dry season when less than 20% of the water passes. Both the calculations and the data in our study (see also 5.4) showed that the contribution from pond effluents to total nutrient content of the river was relatively low on average, though there was an effect on eutrophication.

Though the contribution of effluents from regular refreshment remained relatively low, the discharge of sludge temporarily and locally reduced water quality of the river. This problem can be solved either by letting the sludge settle in the pond or by passing the water through a sedimentation pond (Table 5.1). Sludge left in ponds settles and part of the nutrients mineralise and percolate, or are used by detritivorous organisms in the sludge and the ponds.

The concentrations of pollutants in the wastewater from separated sedimentation ponds, was near to the Vietnamese standard for the quality of discharged water (Table 5.1). The elevation of land by the deposition of the sludge locally compensated for land level decline due to the shrinking of peat soils, and may mitigate the expected effect of rising water level due to climate change. Moreover, recycling the pond sediment may improve both the farms nutrient use efficiency and its financial stability as the waste from feeding fish generates another marketable product (Nhan et al, 2007). The farmers' water and sludge management will determine the contribution to eutrophication and human and freshwater ecotoxicity, and to other aspects of water quality.

Deposition of sludge and sediment on-land or and recycling as manure or fertiliser might improve sustainability of the sector and the farm enterprises, and may contribute to the mitigation of effects from climate change.

If after the culture period the pond sediment is deposited on-land either to fertilise fruit trees or to heighten ground level, nutrients are either used by vegetation or released slowly; in both cases the load in the river will diminish. The nutrient discharge of the ponds in our study would be reduced with more than 90% to 0.14 kg N and to 0.04 kg P per ton fish, respectively. The contribution from the effluent to the total nutrient content in the river water would be reduced to less than 0.05% for both N and P. The remaining sludge and sediment would contain about 2360 kg N and 1060 kg P per ha, which is enough to fertilise 40 ha of rice.

The stakeholders consider that the small integrated farms have accessible possibilities to avoid waste discharge in the river by applying it to their fruit trees or other crops. However the sludge seems too rich for rice and research is needed to formulate recommendations on fertiliser rates and complements. The mono-culture farms having mostly larger ponds in flooding areas need to invest in sludge management and efficient disposal to mitigate environmental impact. A new policy is to concentrate the pangasius farms in some locations to improve waste management. Considering the huge volume of sediment produced the industrial production of fertiliser pellets might be an option which may allow to produce an equilibrated fertiliser at the same time.

Table 5.2 Comparison with effluents from domestic and industrial users of discharge of TSS and COD, and the average / worst case scenario for total N and P from Pangasius ponds in the Mekong river (kg day⁻¹).

Source of waste	Total Suspended Solids (TSS)	N-total	P-total	COD
Domestic (2004)*	237,000	19,800		236,000
Industry (2004) *	4,300	-		6,130
Pangasius (2008)	24,882	5,764 / 21,973	553 / 9,801	21,871

* CMESRC (2004) cited by Nguyen and Thu, 2007.

CMESRC = Center for Marine Environment Survey, Research and Consultation, Hanoi.

5.4 Water quality: seasonal effects and contribution of the sector.

Discharge from ponds is equal or smaller than other sectors but less toxic. Compared to industrial and agricultural waste water, pond effluents contain little substances that are harmful to fish. Mainly the chemicals used for pond preparation and the medicines may contribute to toxicity and other environmental impacts. The discharge from pangasius ponds of COD and TSS is small in relation to the total content in the river, but may be estimated at 10 % of the total anthropogenic waste discharge from domestic users in the Mekong delta (Table 5.2).

In the worst case the sector produces the same quantity of N and P as the domestic users (Table 5.2). Similarly as for COD and TSS, however, anthropogenic contribution to total content of N and P in river water is small. One might therefore conclude that the discharge of nutrients from catfish ponds has no effect. However during sludge discharges, that are concentrated in time, the nutrient output reaches very high levels which might harm water quality locally, especially near ponds located along small canals and away from to the main river and during the dry season when the water flow rate is low.

River water quality in flooding season is not significantly better. The stakeholders assumed that the seasonal high flow rate affected water quality, i.e. reduced the accumulated nutrients in the river. However, the nutrient concentration in the river was not significantly different between the dry and the flood season (Table 5.3). Before 2001, the water quality downstream tended to be better compared to that in the upstream (Hart et al, 2001, see annex E.2). This positive difference has disappeared for some parameters.

Table 5.3 The average and standard deviation of water quality parameters (mg/l), in 2 seasons** and upstream* and downstream* in the rivers Hau and Tien, between 2005 and 2008.

	P-PO₄	N-NO₃	N-NO₂	N-NH₃	COD	DO
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD
Overall	0.13 ±0.19	0.61 ±0.89	0.021 ±0.025	0.21 ±0.39	5.5 ±2.6	6.4 ±2.0
Dry season	0.10 ±0.13	0.67 ±1.13	0.022 ±0.030	0.31 ±0.53	5.7 ±2.6	6.2 ±2.1
Flood season	0.17 ±0.23	0.54 ±0.57	0.020 ±0.020	0.10 ±0.09	5.3 ±2.7	6.7 ±1.9
Upstream	0.15 ±0.21	0.61 ±0.88	0.021 ±0.027	0.23 ±0.41	5.8 ±2.7	6.4 ±2.3
Downstream	0.11 ±0.17	0.60 ±1.91	0.020 ±0.024	0.18 ±0.38	5.2 ±2.6	6.5 ±1.7

* upstream = An Giang and Dong Tap; downstream = Can Tho and Vinh Long.

** The measurements for both were done twice in each; flood season was from June to September.

River water quality has a tendency to decrease especially during dry season. The recent data from RIA-2 (Table 5.3) indicate that COD in the river has doubled (5.5 mg/l) since 2001. It also shows that the sum of N from NO₂, NO₃⁻ and NH₄⁺ alone (average of sum varying from 0.45 to 1.2 mg/l) is most of the year higher than the content in N-total before 2001 (0.7 mg/l, Hart et al, 2001; annex E.2). These recent data thus show that river water quality has a tendency to decrease especially during dry season.

Though fishpond' discharge is less toxic than effluents from other sectors, high seasonal discharge might contribute to the perturbation of aquatic ecosystems and affect other economic sectors.

These increased levels of COD might affect the DO content of the fresh and marine water and thus contribute to the modification of biodiversity. The average dissolved oxygen (DO) content of the water was 6.7 mg O₂ per litre before 2001 and 6.4 mg/l between 2005 and 2008. The DO content was hardly different between upstream and downstream. When DO fell below ≤ 2 mgO₂/l, hypoxia of aquatic environment occurred at which point benthic fauna showed aberrant behaviour, culminating in mass mortality when DO declined below 0.5 mg O₂/liter (Diaz et al, 2008). Some spots of the south China sea showed signs of hypoxia, and also seasonal hypoxia affected the biodiversity of aquatic ecosystems, and thus might negatively impact other economic sectors such as tourism and fisheries. In the past five years no sample contained less than 2 mg O₂/l and in dry season only five out of 54 water samples in the Mekong river were below 4 mgO₂/l, mostly in An Giang. During dry season in An Giang the average is by far the lowest of the four measuring points (Table 5.4; annex E.1).

Though the Mekong river and its' surrounding marine waters do not seem at risk of hypoxia, its water quality tends to decrease seasonally but the impact of pangasius culture is difficult to distinguish from other sectors. As such the pangasius sector might contribute to the perturbation of aquatic ecosystems and affect other economic sectors.

Table 5.4 The average and standard deviation of dry season water quality parameters (mg/l), upstream and downstream in the Hau river, between 2005 and 2008.

		P-PO₄	N-NO₃	N-NO₂	N-NH₃	COD	DO
		Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD
Hau river	Up-	0.13 \pm 0.09	0.51 \pm 0.63	0.62 \pm 0.49	0.04 \pm 0.04	6.5 \pm 3.0	4.5 \pm 1.7
	Down	0.07 \pm 0.09	0.18 \pm 0.29	0.30 \pm 0.31	0.02 \pm 0.20	4.3 \pm 1.2	6.8 \pm 2.2

* upstream = An Giang and Dong Tap; downstream = Can Tho and Vinh Long.

** The measurements for both were done twice in each; flood season was from June to September.

5.5 Land use and biodiversity

The impact on terrestrial biodiversity is limited in the Mekong Delta but may be important in countries producing the feed ingredients. Impact on aquatic biodiversity is hard to distinguish from other causes.

The impact on terrestrial biodiversity in the Mekong Delta was limited, because very little pristine areas were left when the pond culture of catfish developed. Our assumption that the production of rice was not moved to elsewhere because of low margins due to overproduction and farmers' looking for alternative income sources was not invalidated; thus, this conclusion maintains. However, the impact on global deforestation may be important due to the use of soybean and soybean meal from among others Brazil (Annex F, line 48).

Since 2000 pond culture of pangasius developed mainly along the flood protection dikes either on the riverside causing slight loss in biodiversity, or in existing cropland on the landside. The ponds on the riverside occupied less than 0.5% of the flooding area thus hardly reduced the water storage capacity. Along 3.2 km out of 118.5 km of the dikes in areas sensitive to erosion deep ponds were located on the landside of these dikes and these ponds are a hazard for the flood protection.

Though we advised to study the direct impact of catches of fish for feed on aquatic biodiversity, the total impact will nevertheless be hard to specify in an LCA context as appropriate methodology is lacking. The various factors will also be difficult to monitor and therefore the precautionary principle is warranted. The quantification of the long term economic effect of the catches for feed on the catches for human nutrition and the livelihoods of fishermen might influence the decisions of policy makers on catching permits.

The state authorities remain responsible for the effects of the land use for pond construction on biodiversity and on erosion risk, as well as for the reduction of aquatic biodiversity through the catch of fish for fish-feed.

6. Conclusions and recommendations

The results of this study are new for pangasius culture in the Mekong Delta. The LCA showed “hotspots” or key-points to the stakeholders which they can focus on to mitigate the cradle-to-farm-gate environmental impact of the sector. The feed production, which largely takes place outside Vietnam, dominated the environmental impact from the striped catfish production system. Energy, fuel, and transport contributed most of the toxicity impact categories on the feed.

The analysis enabled the researchers to distinguish between the impact of the pangasius culture in the Mekong river and the environmental impact outside the Mekong delta. A considerable part of processes taking place in Vietnam contributed to eutrophication and freshwater ecotoxicity in the Mekong Delta. The contribution of farming was relatively important for water eutrophication and for fresh water ecotoxicity. The contribution of farming to eutrophication depends on whether or not the sludge is discharged in the river.

About 2% of the Mekong river water passed through the pangasius ponds. The effect on water quality was limited because sedimentation, mineralisation, and infiltration occur in ponds. The contribution of the production ponds to water pollution depends on the way farmers manage their sludge. In the worst case, the sector contributes 2.4% to the N and 3.7% to the P content of the river; while on-land sediment recovery and recycling may reduce these to less than 0.05%.

In the Mekong Delta, the effect on land use and terrestrial biodiversity was limited because most land was already cultivated. Land use changes and biodiversity effects from feed production were not included in the study. Using fish for feed remains inefficient (FFE between 0.7 and 2.6). Though the impact on aquatic biodiversity was not only due to the sector, these changes might negatively affect other economic sectors.

The environmental impacts can thus be reduced by producing feed ingredients in the Mekong Delta, by improving the FCR, by reducing the FFE through reducing the % of fishmeal and fishoil in the feed, and by managing the sludge.

Recommendations for policy makers:

- Stimulate production of feed ingredients in the Mekong delta.
- Make compulsory the inclusion of FFE and FCR in the declarations of feed quality, and establish control mechanisms.
- Stimulate Good Management Practices for chemical and medicine use, and improve control on trade of illegal products.
- Stimulate farmers to remove sludge and sediments after harvest only, and to respect other technical conditions of the regulation.

Recommendations for feed producers:

- Produce feed with lower FCRs and FFEs, that also results in sticky faeces that do not easily fall a part in the pond' water.
- Mention the estimated FCR and the FFE on the quality labels.
- Use feed ingredients produced in the Mekong delta.

Recommendations for pangasius farmers:

- Use feed with a low FCR and a low FFE.
- Respect good management practices with regard to chemical and medicine use, and with regard to water, sludge and sediment management.
- Recycle the sludge and sediment as a fertiliser, either by letting the sludge settle in the pond before depositing it on-land, or by using a sedimentation pond if regular removal of sludge is needed, before depositing it on-land.

Recommendations for research:

- Identify an efficient system of waste (water, sludge, and sediment) recycling that produces fertilisers from N and P, and energy from the organic waste.
- Identify the optimal feed composition both for a low FCR, and for faeces with high water stability to optimize nutrient recovery from sludge and sediment.
- Identify the optimal ratio between production and sedimentation in the pond.
- Study the fertiliser value of the sludge and sediment from pangasius ponds, i.e. the complements needed for a recommended dosage for various crops.
- Identify the interesting fish species of the genera *Decapterm* and *Cynoglossus* that might grow-out to a size attractive for human consumption, and tools to prevent their catch for sauce and feed.
- Collect evidence for farmers that using feed with low FCR improves their cost/benefit ratios.
- Collect evidence for both processors and farmers that respecting contracts is at long-term beneficial for them, especially if producers act collectively.
- Quantify the methane emission from the deep pangasius ponds.
- Extend the LCA to include processing, deep-freezing and transport, and overall terrestrial biodiversity; and make a comparison to production elsewhere.
- Make a more thorough LCA of feed production to improve data quality of inventory data, and of alternative feed productions and compositions.
- Make an LCA of the system consequences of proposed environmental improvements in the pangasius sector.

References

- Alkemade, R., M. van Oorschot, C. Nellesmann, L. Miles, M. Bakkenes, B. ten Brink. GLOBIO3: A Framework to investigate options for reducing global terrestrial biodiversity loss. Accepted for publication in *Ecosystems*.
- Amaratna Yakupitiyage, SL Ranamukhaarachchi, Yang Yi & Rahman Mizanur, 2007. Nutrient values of pond sediments. In: Zijpp AJ van der, Verreth JAJ, Le Quang Tri, van Mensvoort M, Bosma RH, Beveridge M. *Fish Ponds in Farming Systems*. Wageningen Acad. Publ. pp89-96.
- Bosma RH, Cao Quoc Nam, HMJ Udo, JAJ Verreth & L Visser, 2006. Farmers' motives for agriculture diversification and its' contribution to livelihoods in the Mekong Delta. *Asian Journal of Agriculture Development*. *Asian Journal of Agriculture and Development*, 2 (1&2) 49-66.
- Boyd CE, C Tucker, A McNevin, K Bostock & J. Clay, 2007. Indicators of Resource Use Efficiency and Environmental Performance in Fish and Crustacean. *Aquaculture Reviews in Fisheries Science*, 15:327–360, DOI: 10.1080/10641260701624177
- CMESRC (2004). National report of marine pollution comes from inland of Vietnam. Center for Marine Environment Survey, Research & Consultation. Institute of Mechanics, Ha Noi. 136 pp.
- Dang K Nhan, MCJ Verdegem, NT Binh, LT Duong, A Milstein, JAJ Verreth, 2008. Economic and nutrient discharge tradeoffs of excreta-fed aquaculture in the Mekong Delta, Vietnam *Agriculture, Ecosystems & Environment*, 124 (3-4) 259-269.
- Dang K Nhan, MCJ Verdegem, A Milstein, JAJ Verreth, 2008. Water and nutrient budgets of ponds in integrated agriculture–aquaculture systems in the Mekong Delta, Vietnam. *Aquaculture Research*, 39 (11) 1216-1228.
- Dang K Nhan, 2007. The role of a fish pond in optimizing nutrient flows in integrated agriculture-aquaculture farming systems. PhD thesis Wageningen University pp 162.
- Diaz RJ & R Rosenberg, 2008. Spreading Dead Zones and Consequences for Marine Ecosystems. *Science* 321: 926-929.
- Energy Information Administration, 2007. Country analysis briefs, Vietnam; retrieved 08-04-2009; www.eia.doe.gov/cabs/Vietnam.
- FAO, 1967. Rice by-products utilization. Informal Working Bulletin No. 30. In: *Animal Feed Resources Information System*, retrieved from <http://www.fao.org/AG/AGA/AGAP/FRG/afris/Data/312.htm>
- Guinée, J. (ed.), 2002: *Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards*. ISBN 1-4020-0228-9 (HB) / ISBN 1-4040-0557-1 (PB). Kluwer Academic Publishers, Dordrecht.
- Hart BT, MJ Jones & G Pistine, 2001. Transboundary water quality issues in the Mekong River Basin. MRC. From internet on 26-03-2009.
- Hauschild, M.Z. & J. Potting (2005): Spatial differentiation in Life Cycle impact assessment - The EDIP2003 Methodology. *Environmental news No. 80* Danish EPA, Copenhagen.
- Hien N.X. 1998. Hydraulic modelling and flood control planning in the Mekong Delta. *Proceedings of the Regional Workshop: Flood management and mitigation in the Mekong River Basin, Vientiane, LAO PDR, March 19th–21st 1998*. <http://www.fao.org/docrep/004/ac146e/AC146E03.htm#chIII.4>
- Hung L.M., Tanaka H., Tu N.T. and Viet N.T. 2006. Prediction of river bank erosion in the Lower Mekong River Delta. Vietnam -Japan Estuary Workshop, Hanoi, Vietnam, August 22nd -24th 2006.
- Kessler, J.J., T. Rood, T. Tekelenburg and M. Bakkenes, 2007. Biodiversity and Socio-Economic Impacts of Selected Agro-Commodity Production Systems. *The Journal of Environment & Development*, 16(2):131-160.
- Nguyen T.D.T., Phung T.B., Vo T.S., Le D.C., 2008. Slide-show of final Report on Vietnam's Biodiversity Assessment and Poverty Linkage Project. Not published.
- Jiménez-Montealegre R, Y Avnimelech, JAJ Verreth & MCJ Verdegem, 2004. Nitrogen budget and fluxes in *Colossoma macropomum* ponds. *Aquaculture Research* Volume 36 Issue 1, Pages 8 – 15.
- Ko I.H. and Lee S.H. 2000. Environment issues for sustainable development of Mekong Delta. KOWACO/KARICO Consultants for Flood Control Planning for Development of the Mekong Delta. kfi.baw.de/conferences/ICHE/2000-Seoul/pdf/101/PAP_129.PDF.
- Le Man Hung, Hitoshi Tanaka, Nguyen Trong Tu & Nguyen Trung Viet, 2006. Prediction of river bank erosion in the lower Mekong river delta. Vietnam-Japan Estuary workshop, Hanoi 22-24 August. pp169-177.

- Le Hong Son, 2003. Power transmission & distribution in Vietnam US Foreign Commercial Service & US Department of State.
- Long P.V.T, 2007. Published in Vietnamese on: www.ATPvietnam.com; last retrieved on 9-04-2009 from: <http://www.atpvietnam.com/vn/thitruongniemyet/4686/index.aspx>.
- Matti Kummu and Olli Varis, 2007. Sediment-related impacts due to upstream reservoir trapping, the Lower Mekong River. *Geomorphology*. Volume 85, Issues 3-4, 30 March 2007, Pages 275-293.
- My An, 2009. Energy for the Mekong Delta. Retrieved from www.ven.vn/industry, 03-04-2009.
- Nguyen Tac An* and Phan Minh Thu Biogeochemical Variability of Vietnamese Coastal Waters Influenced by Natural and Anthropogenic Processes. *Asian Journal of Water, Environment and Pollution*, Vol. 4, No. 1, pp. 37-46.
- Pham Quoc Nguyen, Nguyen Van Cong, Nguyen Van Be, 2008. Sedimentation in *Pangasianodon hypophthalmus* ponds and its potential uses in agriculture in the Mekong delta, Vietnam. Presented at the Symposium on Catfish Aquaculture in Asia. December 5 – 6, 2008.
- Phan Lam, Tam Bui, Thuy Nguyen, G. Gooley, I Brett, Phuong Nguyen, Hao Nguyen, Sena DaSilva, 2009. Current status of farming practices of striped catfish, *Pangasianodon hypophthalmus* (Sauvage) in the Mekong Delta Vietnam. Submitted to *Aquaculture Research*.
- Rattanawan “Tam” Mungkung, 2005. Shrimp Aquaculture in Thailand: Application of Life Cycle Assessment to Support Sustainable Development. PhD thesis CES/SE University of Surrey.
- ReCiPe, 2008. All documents and databases downloadable from <http://lca.wikis.org>.
- Rosenbaum, R.K., T.M. Bachmann, M.Z. Hauschild, M.A.J. Huijbregts, O. Jolliet, R. Juraske, A. Köhler, H.F. Larsen, M. MacLeod, M. Margni, T.E. McKone, J. Payet, M. Schuhmacher, D. van de Meent. USEtox - The UNEP-SETAC toxicity model: Recommended characterisation factors for human toxicity and freshwater ecotoxicity in Life Cycle Impact Assessment. Submitted to *Int. J. of LCA*.
- Tacon, A. G. J., M. R. Hasan, and R. P. Subasinghe, 2006. Use of fishery resources as feed inputs for aquaculture development: trends and policy implications. *FAO Fisheries Circular No. 1018*.
- Thanh D.T., Saito Y., Huy D.V., Nguyen V.L., Ta T.K.O. and Tateishi M. 2004. Regimes of human and climate impacts on coastal changes in Vietnam. *Reg. Environ. Change* (2004) 4:49–62.
- Verdegem M.C.J. & R.H. Bosma, 2009. Water withdrawal for brackish and inland aquaculture, and options to produce more fish in ponds with present water use, *Water Policy Journal*.
- Verdegem M.C.J., R.H. Bosma & JAV Verreth, 2006. Reducing Water Use for Animal Production through Aquaculture. *Water Resources Development*, 22-1, 101–113.
- Vu Anh Tuan and Bach Thi Quynh Mai, 2005. Trash fish use as a food source for major cultured species in An Giang and Dong Thap provinces, Mekong Delta, Vietnam. Internal report RIA-2.

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Annex A: The topics discussed at the Goal and Scoping workshop (August 2008)

During four sessions the following topics were discussed:

1. Round table discussion on the motive: “Why do we need an EIA?”
2. What is the structure of the pangasius production sector.
 - a. Draw the production system (from cradle to grave) and its sub-systems.
 - b. List the main environmental impacts of the pangasius system,
 - c. List its unwanted consequences (trade-offs)
3. List inputs that sub-systems provide to the pangasius farm.
 - a. Draw the sub-systems of the inputs from cradle to pangasius system.
 - b. Where do those inputs to the sub-systems come from?
 - c. Which sub-systems should EIA cover (feed & medicine production, filleting) ?
 - d. What impact do we consider:
 - i. From feed, e.g. impact of catching fish for feed on biodiversity of river and sea ?
 - ii. On natural resources, e.g. the use of brood-stock, land, water ?
 - e. Up to which sub-system should the EIA cover (where is the cradle) ?
4. List outputs and wastes.
 - a. Identify wastes from the subsystems.
 - b. Where and how is waste disposed ?
 - i. Is this the same for locally consumed fish and exported fish ?
 - c. What impacts of waste (pollution) do we consider?
 - i. Water quality / sedimentation / aquatic ecology
 - d. What trade-offs are known and should we consider ?
 - i. Escaped fish, alternative land & water use
 - e. Up to where should the EIA cover : processing / shipping / overseas retail / consumption waste disposal ? In other words: where is the gate?

Annexe B. The team' task distribution for the data collection and data entry of the EIA.

Processes / issues	Study-team members									
	Anh	Ut	Hong	Tuan	Vuong	Minh	Yen	Hanh	Hien	Phong
1. Fish feed farming									X	X
2. Pellet processing						X				
3. Production of lime &									X	X
4. Hatchery		X	X							
5. Pond preparation	=>	X	X							
6. Fish farming	=>	X	X							
7. Transport	X									
8. Power production	X									
9. Erosion/sedimentation				X	X					
10. Siltation & soil pollution				X	X					
11. Change water current &					X					
12. Fish disease, Medicines &							X			
13. Water quality	X	<=		<=	<=					
14. Aquatic ecology &				X						

Legend: * ABR = anti-biotic resistance; X = responsible for data-collection of the sub-system/issue ;
 <=> will deliver data to the responsible person.

Annexe C.1. Classification for qualification of data requirement (manual Sima Pro 7, p.31)

Score:	1	2	3	4	5
U1 Reliability	Verified data based on measurements	Verified data partly based on assumptions OR non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert); data derived from theoretical information (stoichiometry, enthalpy, etc.)	Non-qualified estimate
	1.00	1.05	1.10	1.20	1.50
U2 Completeness	Representative data from all sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered OR >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered OR some sites but from shorter periods	Representativeness unknown or data from a small number of sites AND from shorter periods
	1.00	1.02	1.05	1.10	1.20
U3 Temporal correlation	Less than 3 years of difference to our reference year (2000)	Less than 6 years of difference to our reference year (2000)	Less than 10 years of difference to our reference year (2000)	Less than 15 years of difference to our reference year (2000)	Age of data unknown or more than 15 years of difference to our reference year (2000)
	1.00	1.03	1.10	1.20	1.50
U4 Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from smaller area than area under study, or from similar area		Data from unknown OR distinctly different area (north america instead of middle east, OECD-Europe instead of Russia)
	1.00	1.01	1.02		1.10
U5 Further technological correlation	Data from enterprises, processes and materials under study (i.e. identical technology)		Data on related processes or materials but same technology, OR Data from processes and materials under study but from different technology	Data on related processes or materials but different technology, OR data on laboratory scale processes and same technology	Data on related processes or materials but on laboratory scale of different technology
	1.00		1.20	1.50	2.00
U6 Sample size	>100, continuous measurement, balance of purchased products	>20	> 10, aggregated figure in env. report	>=3	unknown
	1.00	1.02	1.05	1.10	1.20

Source: PRé Consultants, 2008. Introduction to LCA, Manual SimaPro 7.

Annex C.2. Criteria used to check of the LCA results

Determination of the influence on results of variations in assumptions, methods and data (sensitivity check):	Evaluation whether assumptions, methods, models and data are <u>consistent</u> within and between product systems with regard to:
<ul style="list-style-type: none"> ▪ Rules for allocation ▪ Cut-off criteria ▪ Boundary settings and system definition ▪ Judgement and assumptions concerning data ▪ Selection of impact categories ▪ Assignment of inventory data ▪ Calculation of category indicators ▪ Normalised data ▪ Weighted data ▪ Weighting method ▪ Data quality 	<ul style="list-style-type: none"> ▪ Data sources ▪ Data accuracy ▪ Technology coverage ▪ Time related coverage ▪ Geographical coverage ▪ Age of data ▪ Assignment of inventory data ▪ Calculation of category indicators ▪ Normalised data ▪ Weighted data ▪ Weighting method ▪ Data quality

Annex D: Data on feed ingredients from the 5 companies and of shrimp processing.

Table D.1 The quantities of ingredients used for catfish feed by 5 companies (tonnes/year), and the average composition of catfish feed for company B, C, D and E (for A see table 3.4).

Ingredient	Countries of origin	Feed company					Average B-E %
		A	B	C	D	E	
Fish meal	VN, Indonesia, India, Myanmar	23040	10800	7200	15750	4900	12.8
Soybean meal	VN, India, USA, Arg., Brazil	44160	14400	13800	24150	8750	20.7
Rice bran	VN, Thailand, India	44160	17280	14400	24150	8750	21.9
Rice meal	VN, Thailand, India	21120	7200	7800	11550	4550	10.7
Wheat bran	China, India, Germany	24960	10080	9000	14700	5250	13.2
Cassava powder	VN, China, India	36480	14400	12000	21000	6650	18.0
Fish oil	VN, China	3840	1656	1200	2100	700	1.9
Others	China, France, India	1536	576	480	840	280	0.7

Legend: VN= Viet Nam; Arg. = Argentina; Others = vitamins, minerals, anti-oxydants, inorganics.

Table D.2 Inputs and outputs for processing shrimp to produce frozen shrimps

	Items and unit	Quantity per 1.8 kg frozen	Quantity per ton fresh shrimp
Inputs	Shrimp (kg)	3	1,667
	Water, for processing (l)	25	13,889
	Plastic bag (g)	9	5,000
	Paper box (g)	17	9,444
	Ice (kg)	2.44	1,356
	Electricity (kWh) ¹	1.56	867
Outputs	Suspended Solids (mg)	1.45 E-03	0.81
	BOD (mg)	8.68 E-04	0.48
	Total N (mg)	7.13 E-04	0.40
	Total P (mg)	9.22 E-04	0.51
	Shrimp waste (kg)	1.2	667

Source: Anonymous (2003a), cited by Rattanawan, 2005

1: The figure is the total energy consumption, which includes: 0.4 kWh by the compressor; 0.6 kWh by the cold storage; 0.5 kWh by the icemaker; 0.02 kWh by the water-spraying (for adding water into the blocks); 0.01 kWh by the waterspraying (for the block removal); and 0.03 kWh by the lights of the working area.

Annex E: Data on water quality of the fish ponds and the Mekong River

Table E.1 The water quality at 2 points in 2 main branches of the Mekong river 2005 to 2008 (mg/l)

River	Dry season				Flooding season			
	Upstream		Downstream		Upstream		Downstream	
	Tien ¹	Hau ²	Tien ³	Hau ⁴	Tien ¹	Hau ²	Tien ³	Hau ⁴
COD	6.5	6.2	4.3	5.6	5.1	5.2	5.1	5.9
DO	7.6	4.7	6.0	6.8	6.9	6.7	6.7	6.4
N – NO ₃	0.62	0.90	0.30	0.86	0.33	0.46	0.63	0.45
N – NO ₂	0.040	0.005	0.019	0.021	0.019	0.021	0.026	0.015
N – NH ₃	0.51	0.23	0.18	0.32	0.10	0.08	0.15	0.08
P- PO ₄ ³⁻	0.12	0.07	0.07	0.12	0.21	0.21	0.15	0.12

Downstream are Can Tho (4) and Vinh Long (3), Upstream are An Giang (2) and Dong Tap (1).

Table E.2 The water quality at 2 points in 2 main branches of the Mekong river before 2001 (average and 10th and 90th percentile values in mg/l)

River	Upstream		Downstream	
	Tien (Tan Chau)	Hau (Chau Doc)	Tien (My Thuan)	Hau (CanTho)
DO *	6.6 (5.9 – 7.2)	7.0 (6.1 - 7.5)	6.8 (6.0 - 7.4)	6.5 (5.9-7.5)
COD *	2 (0.8 - 5.2)	2.4 (0.8 - 4.6)	2 (1 - 4.6)	2.4 (1-5)
N-total *	0.7 (0.3-1.1)	0.6 (0.35-1.3)	0.65 (0.3-1.15)	0.7 (0.4-1.3)
P- total *	0.1 (0.040 - 0.26)	0.08 (0.04 – 0.19)	0.09 (0.04 – 0.2)	0.09 (0.05-0.18)
P- PO ₄ ³⁻				

* Hart et al, 2001

Table E.3 Estimated pollution from effluent water per kg of fish of 30 catfish farms in four provinces in the MD, based on average water quality of 9 other farms in 3 provinces (mean ± SD).

Item	Unit	Can Tho	Vinh Long	Dong Thap	An Giang	All farms
DO		419 ± 149	2738 ± 1445	1392 ± 1255	544 ± 521	1165 ± 1221
BOD ₅	mg kg ⁻¹ fish	261 ± 93	2415 ± 1275	1019 ± 919	510 ± 488	944 ± 1013
COD	mg kg ⁻¹ fish	466 ± 165	5067 ± 2675	1981 ± 1785	1306 ± 1250	1989 ± 2095
N-NH ₃	mg kg ⁻¹ fish	130 ± 46	758 ± 400	412 ± 371	333 ± 319	395 ± 361
NO ₂	mg kg ⁻¹ fish	6 ± 2	254 ± 134	66 ± 60	11 ± 10	67 ± 102
NO ₃	mg kg ⁻¹ fish	230 ± 81	1584 ± 836	781 ± 704	178 ± 171	611 ± 711
Total N *	mg kg ⁻¹ fish	865 ± 306	9419 ± 4973	3679 ± 3315	1177 ± 1126	3279 ± 3918
Total P *	mg kg ⁻¹ fish	146 ± 52	1841 ± 972	675 ± 608	423 ± 404	685 ± 750

* In the LCA these were corrected for the nutrient content in the inlet water.

Annex F. The farm-gate life cycle inventory table, according to Recipe Midpoint (E) V1.01 / World, for producing 1 ton Pangasius using the average feed composition, while including other inputs than feed in the farming with the worst case sludge management, and energy in each of the processes.

* Substances with an impact lower than the mentioned units were excluded from this table, which explains the discontinuity in the numbering.

No*	Substance	Compartment	Unit	Total	Transport	Farming	Feed
28	Aluminium, 24% in bauxite, 11% in crude ore, in ground	Raw	g	832.18 x		831.65	0.53
30	Aluminum	Water	g	80.30	0.17	40.05	40.08
31	Aluminum	Soil	g	21.19	0.01	0.44	20.74
34	Ammonia	Air	kg	12.51	0.00	0.00	12.51
35	Ammonia, as N	Water	g	25.59	0.01	0.49	25.09
48	Arable land use, soy bean, Argentina	Raw	m2a	581.09 x		x	581.09
55	Barite	Water	g	318.59	0.13	6.11	312.34
56	Barite, 15% in crude ore, in ground	Raw	g	44.39 x		19.12	25.27
58	Barium	Water	g	47.75	0.03	1.12	46.60
62	Baryte, in ground	Raw	kg	1.60	0.00	0.03	1.57
64	Bauxite, in ground	Raw	g	130.01	11.39	2.08	116.53
69	Benzene	Air	g	6.82	0.03	0.13	6.67
70	Benzene	Water	g	2.35	0.00	0.05	2.29
80	BOD5, Biological Oxygen Demand	Water	g	263.37	0.01	59.20	204.17
90	Butane	Air	g	28.92	0.01	0.67	28.25
103	Calcite, in ground	Raw	g	711.82 x		586.13	125.69
105	Calcium	Soil	g	84.90	0.04	1.86	83.01
106	Calcium, ion	Water	g	770.53	0.49	47.28	722.76
109	Carbon	Soil	g	65.74	0.03	1.41	64.30
112	Carbon dioxide	Air	kg	1,656.20	0.45	9.75	1,646.00
113	Carbon dioxide, biogenic	Air	g	495.81 x		407.48	88.33
114	Carbon dioxide, fossil	Air	kg	31.61 x		13.04	18.57
115	Carbon dioxide, in air	Raw	g	519.76 x		424.59	95.17
116	Carbon dioxide, land transformation	Air	g	1.89 x		1.61	0.27
118	Carbon monoxide	Air	kg	2.17	0.00	0.01	2.16
120	Carbon monoxide, fossil	Air	g	54.18 x		14.17	40.01
123	Carboxylic acids, unspecified	Water	g	2.03 x		0.67	1.36
135	Chlorate	Water	g	2.06 x		2.06	0.00
136	Chloride	Water	kg	10.27	0.01	0.33	9.93
137	Chloride	Soil	g	1.59 x		1.01	0.58
153	Chromium, 25.5% in chromite, 11.6% in crude ore, in ground	Raw	g	5.53 x		5.31	0.22
154	Chromium, in ground	Raw	g	6.74	0.45	0.11	6.18
158	Clay, bentonite, in ground	Raw	g	165.08	0.59	7.27	157.23
159	Clay, unspecified, in ground	Raw	g	805.86	0.29	317.46	488.11
160	Coal, 18 MJ per kg, in ground	Raw	kg	22.84	0.11	1.00	21.73
161	Coal, brown, 8 MJ per kg, in ground	Raw	kg	9.24	0.06	0.17	9.01
162	Coal, brown, in ground	Raw	kg	3.26 x		2.11	1.15
163	Coal, hard, unspecified, in ground	Raw	kg	2.33 x		1.54	0.79
174	COD, Chemical Oxygen Demand	Water	g	179.65	0.06	52.20	127.39
179	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	Raw	g	3.55 x		3.34	0.22
181	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	Raw	g	4.71 x		4.43	0.28
182	Copper, in ground	Raw	g	26.92	0.76	0.34	25.82
195	Dinitrogen monoxide	Air	kg	12.46	0.00	0.00	12.46
197	DOC, Dissolved Organic Carbon	Water	g	39.22	0.00	17.12	22.10
198	Dolomite, in ground	Raw	g	1.23 x		0.73	0.50
199	Energy, from coal	Raw	GJ	1.62 x		x	1.62
200	Energy, from coal, brown	Raw	MJ	159.94 x		x	159.94
201	Energy, from gas, natural	Raw	GJ	8.33 x		x	8.33
202	Energy, from hydro power	Raw	MJ	99.16 x		x	99.16
203	Energy, from oil	Raw	GJ	2.50 x		x	2.50
204	Energy, from uranium	Raw	MJ	333.86 x		x	333.86
205	Energy, gross calorific value, in biomass	Raw	MJ	5.31 x		4.42	0.89

206 Energy, gross calorific value, in biomass, primary forest	Raw	J	587.97 x		254.57	333.39
207 Energy, kinetic (in wind), converted	Raw	MJ	1.78 x		1.30	0.47
208 Energy, potential (in hydropower reservoir), converted	Raw	MJ	216.83	0.38	158.49	57.97
209 Energy, solar, converted	Raw	kJ	19.20 x		12.43	6.77
210 Ethane	Air	g	15.77	0.01	0.66	15.10
225 Ethene	Air	g	9.48	0.70	0.23	8.55
240 Fatty acids as C	Water	g	88.72	0.04	1.50	87.18
243 Fish, unspecified, in sea	Raw	ton	1.11 x	x		1.11
244 Fluoride	Water	g	5.91	0.01	3.11	2.79
249 Fluorspar, 92%, in ground	Raw	g	1.50 x		1.05	0.45
252 Formaldehyde	Air	g	10.20	0.00	0.05	10.15
258 Gas, mine, off-gas, process, coal mining/kg	Raw	g	152.29	0.80	6.17	145.31
259 Gas, mine, off-gas, process, coal mining/m3	Raw	l	22.69 x		15.01	7.69
260 Gas, natural, 35 MJ per m3, in ground	Raw	m3	51.34	0.02	0.38	50.94
261 Gas, natural, in ground	Raw	m3	2.98 x		2.46	0.52
262 Gas, petroleum, 35 MJ per m3, in ground	Raw	m3	23.92	0.01	0.40	23.50
275 Gravel, in ground	Raw	kg	36.11	0.01	6.87	29.23
277 Heat, waste	Air	MJ	7,365.72	7.31	316.66	7,041.75
278 Heat, waste	Water	MJ	714.93	0.69	12.36	701.88
279 Heat, waste	Soil	MJ	7.97	0.02	1.64	6.31
280 Helium	Air	g	24.12	0.01	0.41	23.69
282 Heptane	Air	g	6.39	0.00	0.14	6.25
283 Hexane	Air	g	-151.21	0.00	0.31	-151.53
285 Hydrocarbons, aliphatic, alkanes, unspecified	Air	g	9.63	0.00	0.23	9.39
286 Hydrocarbons, aliphatic, alkanes, unspecified	Water	g	2.34	0.00	0.06	2.28
292 Hydrocarbons, aromatic	Water	g	10.76	0.00	0.26	10.50
298 Hydrogen chloride	Air	g	60.98	0.05	1.36	59.57
299 Hydrogen fluoride	Air	g	1.54	0.01	0.14	1.40
305 Hypochlorite	Water	g	1.67	0.00	0.01	1.67
306 Hypochlorous acid	Water	g	1.67	0.00	0.00	1.66
308 Iodide	Water	g	1.80	0.00	0.05	1.75
318 Iron	Water	g	33.45	0.15	0.88	32.42
319 Iron	Soil	g	43.21	0.02	1.67	41.53
322 Iron, 46% in ore, 25% in crude ore, in ground	Raw	g	513.78 x		302.76	211.02
323 Iron, in ground	Raw	kg	4.43	0.05	0.05	4.33
324 Iron, ion	Water	g	12.92 x		8.98	3.94
334 Land use II-III	Raw	m2a	3.40	0.02	0.06	3.32
335 Land use II-III, sea floor	Raw	m2a	25.40	0.01	0.42	24.97
336 Land use II-IV	Raw	m2a	1.90	0.57	0.03	1.30
337 Land use II-IV, sea floor	Raw	m2a	2.62	0.00	0.04	2.58
338 Land use III-IV	Raw	m2a	2.05	0.00	0.04	2.01
350 Lead, in ground	Raw	g	25.30	4.88	0.31	20.12
355 Magnesite, 60% in crude ore, in ground	Raw	g	6.97 x		4.13	2.84
357 Magnesium	Water	g	67.16	0.15	6.20	60.80
362 Manganese	Water	g	1.98	0.00	0.15	1.82
367 Manganese, in ground	Raw	g	2.19	0.10	0.04	2.04
368 Marl, in ground	Raw	kg	13.20	0.02	10.41	2.78
374 Methane	Air	kg	153.87	0.00	0.03	153.84
385 Methane, fossil	Air	g	39.06 x		25.19	13.87
392 Methanol	Air	g	1.22	0.00	0.03	1.19
419 Nickel	Air	g	2.08	0.00	0.04	2.04
422 Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	Raw	g	17.77 x		15.44	2.33
423 Nickel, in ground	Raw	g	4.06	0.30	0.06	3.70
428 Nitrate	Water	kg	158.57	0.00	0.03	158.54
429 Nitrite	Water	g	1.74	0.00	1.71	0.03
430 Nitrogen	Air	g	14.06	0.01	0.11	13.95
433 Nitrogen oxides	Air	kg	11.28	0.00	0.05	11.23
434 Nitrogen, organic bound	Water	g	5.29	0.00	0.15	5.14
435 Nitrogen, total	Water	kg	8.18	0.00	8.02	0.16
436 NMVOC, non-methane volatile organic compounds,	Air	kg	3.28	0.00	0.05	3.23
439 Occupation, arable	Raw	m2a	17,815.42 x		0.00	17,815.42
445 Occupation, forest, intensive, normal	Raw	m2a	0.33 x		0.28	0.05

459 Occupation, water bodies, artificial	Raw	m2a	0.25 x		0.16	0.09
461 Oil, crude, 42.6 MJ per kg, in ground	Raw	kg	350.22	0.15	5.92	344.15
462 Oil, crude, in ground	Raw	kg	7.42 x		2.49	4.93
464 Oils, unspecified	Water	g	354.57	0.15	15.67	338.76
465 Oils, unspecified	Soil	g	48.46	0.01	10.98	37.48
474 Particulates	Air	g	770.63 x			770.63
475 Particulates, < 10 um (mobile)	Air	g	63.21	0.01	0.30	62.91
476 Particulates, < 10 um (stationary)	Air	g	138.38	0.17	1.20	137.01
477 Particulates, < 2.5 um	Air	g	12.29 x		4.54	7.75
478 Particulates, > 10 um	Air	g	23.54 x		11.51	12.03
479 Particulates, > 10 um (process)	Air	g	164.01	0.55	96.78	66.68
480 Particulates, > 2.5 um, and < 10um	Air	g	14.81 x		6.78	8.03
481 Particulates, diesel soot	Air	g	98.99 x			98.99
482 Particulates, unspecified	Air	g	100.27 x			100.27
486 Pentane	Air	g	36.28	0.01	0.83	35.44
490 Phenols, unspecified	Water	g	2.23	0.00	0.04	2.20
491 Phosphate	Water	kg	3.89	0.00	0.00	3.89
492 Phosphate ore, in ground	Raw	kg	745.52 x			745.52
495 Phosphorus	Water	g	5.60 x		5.60	0.00
501 Phosphorus, total	Water	kg	3.58 x		3.58	0.00
517 Potassium	Air	g	1.16	0.01	0.11	1.05
518 Potassium	Water	g	98.17	0.09	1.95	96.13
522 Potassium, ion	Water	g	3.88 x		1.92	1.96
526 Propane	Air	g	29.61	0.01	0.76	28.84
527 Propene	Air	g	1.43	0.00	0.04	1.39
558 Salts, unspecified	Water	g	33.57	0.22	0.62	32.74
560 Sand, unspecified, in ground	Raw	kg	1.71	0.00	0.02	1.69
566 Silicates, unspecified	Air	g	1.37 x		0.02	1.35
568 Silicon	Water	g	237.57	0.00	211.66	25.91
581 Silver, in ground	Raw	g	1.12	0.00	0.02	1.10
583 Sodium	Air	g	2.63	0.00	0.05	2.58
587 Sodium chloride, in ground	Raw	kg	2.96	0.00	2.52	0.43
594 Sodium, ion	Water	kg	6.10	0.00	0.21	5.88
595 Solids, inorganic	Water	g	14.61 x		10.46	4.15
597 Solved substances	Water	g	15.48	0.07	0.69	14.72
600 Strontium	Water	g	107.35	0.05	2.19	105.11
608 Sulfate	Water	g	685.59	1.42	80.15	604.02
612 Sulfur	Soil	g	12.74	0.01	0.27	12.46
613 Sulfur dioxide	Air	kg	3.93 x		0.05	3.88
615 Sulfur oxides	Air	kg	4.34	0.00	0.03	4.31
617 Sulfur, in ground	Raw	kg	49.58 x		0.00	49.58
620 Suspended solids, unspecified	Water	g	15.81 x		11.20	4.62
653 TiO2, 54% in ilmenite, 2.6% in crude ore, in ground	Raw	g	1.73 x		0.71	1.03
657 Titanium, ion	Water	g	14.36	0.01	12.13	2.22
658 TOC, Total Organic Carbon	Water	g	385.06	9.31	23.03	352.72
659 Toluene	Air	g	4.44	0.00	0.11	4.33
660 Toluene	Water	g	1.97	0.00	0.05	1.91
719 Undissolved substances	Water	g	983.85	0.46	16.27	967.12
731 Vanadium	Air	g	6.49	0.00	0.12	6.36
735 VOC, volatile organic compounds	Air	g	16.52 x			16.52
736 VOC, volatile organic compounds as C	Water	g	6.12	0.00	0.10	6.01
740 Volume occupied, reservoir	Raw	m3y	7.44	0.01	6.16	1.28
745 Water, river	Raw	m3	3.07 x		3.05	0.02
748 Water, turbine use, unspecified natural origin	Raw	m3	389.65	1.96	86.74	300.96
749 Water, unspecified natural origin/kg	Raw	kg	19,298.37	12.39	67.61	19,218.38
751 Water, well, in ground	Raw	m3	74.57 x		0.01	74.55
752 Wood, dry matter	Raw	kg	1.03	0.01	0.01	1.01
764 Xylene	Air	g	3.19	0.03	0.10	3.06
765 Xylene	Water	g	1.70	0.00	0.04	1.66
771 Zinc, 9.0% in sulfide, Zn 5.3%, Pb, Ag, Cd, In, in ground	Raw	g	2.34 x		2.27	0.08
773 Zinc, ion	Water	g	1.12	0.01	0.15	0.96

Category	Name/description	Unit	Quantity	Source of information	Calculations/comments
Economic inputs	Energy	Electricity	Kwh/yr		
		Gasoline	ltr/yr		
		Diesel	ltr/yr		
		Wood	cubic m/year		
		Other (specify which)	unit?		
		Land area occupied	square m/year		
		Tap water	cubic m/year		
		(Raw)	unit?		
		materials	unit?		
			unit?		
		Chemical	unit?		
		(specify which)			
		unit?			
		unit?			
	Ingredients	unit?			
	(specify	unit?			

Category	Name/description	Unit	Quantity	Source of information	Calculations/comments
Environmental inputs	Abiotic	Ground water	cubic m/year		
		Fresh surface water	cubic m/year		
	Biotic	Wood (specify type)	cubic m/year		
		Wild broodstock	kg/year		
		Trash fish river	tons/year		
		Trash fish marine	tons/year		
		Others	unit?		

